ABSTRACT

TOU, NECIA ANN. An Investigation of Arcing in Two Structure Weft Knit Fabrics (Under the direction of Prof. Nancy Powell (Chair), Dr. Traci May-Plumlee (Co-chair))

There is a wide range of products such as football jerseys, sweaters, compression bandages, filters, bulletproof vests, and fluid absorbing sheets that contain different knit structures as part of their constructions. The construction provides each product its optimum performance characteristics. Due to the technological advancement of computerized knitting machinery, it is possible to knit different structures side-by-side, rather than in a sequential manner. The purpose of this thesis is to investigate the occurrence of one type of fabric distortion, arcing, when two different structures are knitted side-by-side. Arcing refers to the bending of wales in a knitted fabric.

Three weft knit structures were selected for this research (single jersey, 1x1 rib, and the moss stitch) because they represent the basic single weft knit structure groups: jersey, rib, and purl. This thesis investigates these three structures in fabrics where abutted areas are composed of the combination of any two different structures. The effects of changes in loop length, yarn type, and fiber type on physical properties of dry-relaxed two-structure fabrics are investigated, and the results were discussed with reference to arcing. The potential problems and characteristics of single jersey, 1x1 rib, and the moss stitch structures were examined and their influences on each other were studied.

The results indicated that arcing occurred when two different structures were knitted side-by-side and arcing was effected by the combination of specific

structures. It was determined that structural stability contributed highly to the amount of arcing. Fabrics knitted tightly were more susceptible to arcing than the medium knit fabrics, though tight, medium and loose knit fabrics all exhibited arcing. Fabric arcing was also influenced by yarn type. It was determined that spun yarns produced more arcing than filament yarns.

AN INVESTIGATION OF ARCING IN

TWO STRUCTURE WEFT KNIT FABRICS

by

NECIA ANN TOU

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To my mother *Wen Chi*,

to my father *Jerry*,

to my brother *Nicholas*,

and to my sister *Nicole*.

BIOGRAPHY

Necia Ann Tou was born in Newark, Ohio on May 14, 1979. Her parents are Jerry and Wen Chi Tou and she has one brother and one sister, Nicholas and Nicole.

Necia graduated from Scotland High School in Laurinburg, NC in 1997. In May 2002, she received her B.S. in Textile Technology and minors in Art & Design and Chinese Studies from North Carolina State University, College of Textiles.

Necia continued her studies at NCSU College of Textiles and is presently in completion of M.S. in Textile and Apparel Technology and Management degree. As a graduate student, she spent summer of 2004 at the Design Center at Milliken & Company in the warp knit sector of automotive interiors. She plans to travel far and wide to savor her taste in textiles.

ACKNOWLEDGEMENTS

I owe thanks and my sincerest gratitude to the members of my advisory committee for their invaluable knowledge and encouragement in the execution and completion of this research. I thank Prof. Nancy B. Powell for her consistent enthusiasm and compassionate guidance. I thank Dr. Traci May-Plumlee for her strength, dependability, and intuitiveness. I thank Dr. Gary W. Smith for his invaluable advice and keen criticisms.

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GLOSSARY OF TERMS

1x1 rib	Fabric formed on two sets of needles producing a balanced fabric, identical loops on both sides
c.p.i.	The number of courses (horizontal rows) per square inch
Course	A horizontal row of loops
Course length	The average length of yarn to knit a course
Denier	grams per 9,000 meters (9 km)
dtex (decitex)	grams per 10,000 meters (10 km)
d.p.f	Denier per filament
FB and BB	Front bed and back bed (v-bed)
Filament	A strand of continuous length
Filament yarn	A composition of single filaments or multiple filaments which form a yarn
Float stitch	Miss stitch
Gaiting	Describes needle arrangement: interlock (head to head), rib (heads are offset)
Jersey	The simplest knit structure, fabric formed on one set of needles which produces an unbalanced fabric
Knit stitch	Face loop
Links-links	Generally applied to purl fabrics and machines
Negative feed	Using yarn as its needed by the amount of yarn pulled down by needles
n.p.i	The number of needles per inch
Ply yarn	Composed of 2 or more single yarns twisted together
Positive feed	Pre-metering device, loop size remain unchanged and therefore cpi, wpi, and fabric properties remain consistent
Purl	Fabric consisting of alternating course loops from the face to the rear to produce identical loops on both sides
Purl stitch	A basic knitting stitch consisting of a front loop then a back loop
Single yarn	A composition of staple fibers or filaments bound together to form a yarn
Spun yarn	A yarn composed of staple fibers held together by some binding mechanism
Stitch density	Number of (courses x wales) per unit area
Technical face	The side of the fabric intended to be visible on the end product
Technical back	The reverse side of the fabric; not visible on the end product
Thread	Used to join pieces of fabrics together
Tuck stitch	Held loop
w.p.i.	The number of wales (vertical columns) per square inch
Wale	A vertical column of loops
Yarn	A continuous strand of textile fibers that may be composed of filaments or staple fibers held together.

CHAPTER I: INTRODUCTION

Wide ranges of weft knitted products are used for apparel, industrial, and medical purposes. Products such as football jerseys, sweaters, compression bandages, filters, bulletproof vests, and fluid absorbing sheets may all contain different knit structures as part of their constructions. The construction provides each product its optimum performance characteristics. This thesis investigates the use of single jersey, 1x1 rib, and a selected purl structure in combination fabrics containing a joined area composed of two abutted knit structures.

In this context there has been minimal research investigating structures that are joined side-by-side, rather than in a sequential manner in terms of the precise relationships that exist between them. Figures 1.1 illustrate two fabric positions, where the dotted line represents the area where two different structures meet, in a side-by-side and sequential manner. The wale direction is vertical and course direction is horizontal in both illustrations. The side-by-side arrangement will be the focus of this research.

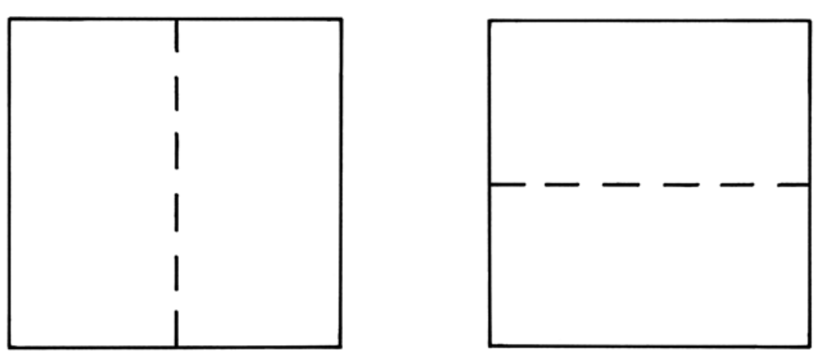


Figure 1.1: Side-by-side and sequential

The interaction of structures may cause deformation such as arcing when structures are adjoined. The degree of deformation may limit structure combinations knitted on the machine when certain aesthetics and functions are desired.

1.1 Purpose of Study

The objective of this research was to study structure interactions when knit structures were knitted side-by-side. This was accomplished by analyzing the properties of one-structure weft knit fabrics compared with two-structure weft knit fabrics. In the two-structure fabrics created for this work, there were clearly two different structures present and they were not intermingled. Fabric distortions were expected to occur when two structures were knitted side-by-side. The interactions between structures may cause the fabric to arc.

Research Questions

There were two research questions to guide this work.

1. Does arcing occur when different weft knit structures are knitted side-by-side in a single fabric?
2. How do loop length, structure combination, yarn type, and fiber type impact arcing?

1.2 Rationale

Due to the advancement of knitting technology, different knit structures can be knitted simultaneously. Many types of industries, including apparel, industrial, and medical applications, use knit fabrics because of their ability to conform to any dimension. In slimming hosiery, functionality is significant for shaping and lifting all types of body shapes (Shop, 2004).

This flexible, elastic fabric adapts easily to body movement which makes it ideal for close fitting garments like orthopedic braces, compression gloves, hosiery, and athletic wear. Precise products are necessary and higher performance standards are required for highly technical products such as skin grafts and vascular grafts (Smith, 2004). But, there is minimal published information available concerning fabric distortions when different structures are knitted side-by-side. Knit fabrics of specific structures have unique properties that may be changed if one structure is knitted side-by-side with another structure.

1.3 Limitations

The yarn deniers used in this research were not identical for all four yarns, but yarns were matched as closely as possible. Therefore, the denier of each yarn and yarn type are addressed when analyzing yarn effects on arcing.

Negative feed was also a limitation. The results may have been influenced by negative feed and cannot be generalized to fabrics constructed using positive feed. This feeding system was used to draw the necessary amount of yarn to produce the two-structure fabric rather than pre-metering the amount of yarn because loop differences between two different knit structures were difficult to predict.

CHAPTER TWO: LITERATURE REVIEW

The objective of this research was to study structure interactions when weft knit structures were knitted side-by-side. This was accomplished by analyzing the influence of loop length, structure combination, yarn type, and fiber type in two-structure knit fabrics. When two structures are knitted side-by-side, some degree of fabric deformation can be expected due to structural interaction.

Structural interactions are significant especially on computer controlled v-bed machines because fabric design has evolved to more complex knitting techniques resulting in new structures and complex patterns. Structure change is no longer limited, unlike in the past when it was only possible in successive courses of knitting.

The two general elements required for knitting structures side-by-side are: independent needle selection and latch needles with transfer latches (Shima Seiki, 2004). Independent needle selection is the most versatile and widely used method of knitting designs that consist of different structures. Latch needle weft knitting machines are especially suitable for knitting different structures in a side-by-side manner because the needles are individually controlled to allow for independent movement (Spencer, 2001). This allows more than one type of stitch to be produced in the same wale or adjacent wales, which contributes to versatile design capability.

According to Spencer (2001), the latch needle has an advantage of being self-acting or loop controlled which means that individual movement and control of the needle enables stitch selection to be achieved. The transfer latch located along the stem of the latch needle allows the transfer of loops from one bed to another.

The function of the transfer latch is significant in allowing the purling action on the v-bed. It is ideally suited for use with computer-controlled electronic selection devices. For this reason, it is the most widely used needle in weft knitting. The independent needle action is one knitting element that contributes to the machine's ability to knit different structures side-by-side.

There has been no literature precisely related to this study. Only general finds were available through literature search and there were no particular tests or research projects found to be related to this topic. However, certain parameters related to knit structures were of interest:

a. Potential fabric tightness influences
b. Potential structure interactions
c. Potential yarn type influences
d. Potential fiber density influences

So, the literature review focuses on those parameters and their potential implications for knit structures.

2.1 Introduction to Knitting Machinery

Knitting is the process of forming fabric by interlooping yarn in a series of connected loops using needles. Knit fabrics provide outstanding comfort qualities and have long been preferred in many types of clothing. In addition to comfort imparted by the extensible looped structure, knits also provide lightweight warmth, wrinkle resistance, and ease of care. Depending on desired aesthetics, hand and performance, knit fabrics can be produced by one of two basic knitting technologies: weft knitting and warp knitting.

In weft knitting, loops are formed width-wise or horizontally across the width of the fabric (Hatch, 1993), shown in Figure 2.1. These fabrics can be produced either in circular or open-width form. Each vertical column of loops is called a wale and an associated horizontal row of loops is called a course. These fabrics are generally highly elastic and highly drapeable. These two attributes make them suitable for a wide range of apparel applications.

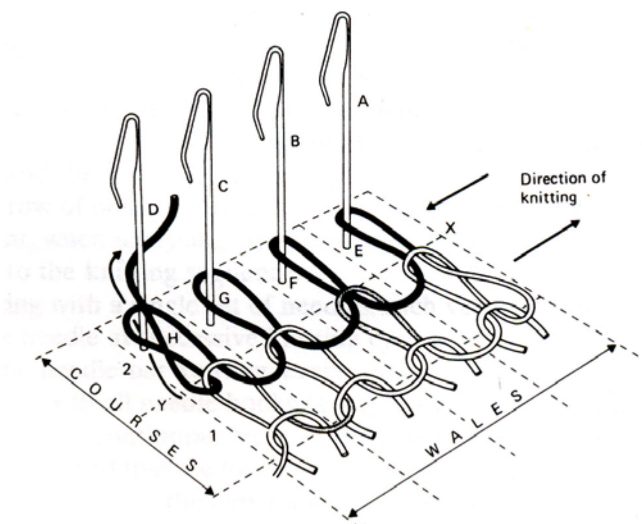


Figure 2.1: Width-wise knitting direction (Spencer, 2001)

The weft knit machine by Shima Seiki utilized in this thesis is shown in Figure 2.2, with four packages of yarn set on top of the machine. There are a variety of weft knitting machines that have the ability to produce the three structures studied in this research: single cylinder, cylinder and dial, purl, and v-bed.

Figure 2.2: V-bed weft knit machine (Shima Seiki, 2004)

The simplest weft knitting machine is the single cylinder machine or circular jersey machine, as shown in Figure 2.3. This type of machine can only produce one type of base structure, such as single jersey or its derivative fabrics (Smith, 2004). Most fabric is knitted on circular machines with revolving needle cylinder type due to high speed and production (Spencer, 2001). This is a result of having one needle bed, which can only produce knit, tuck or float stitches. The yarn is supplied from packages over the needle bed. Because only knit stitches need to be made for the production of the single jersey structure, the knitting element consists of only one needle bed, latch needles are arranged vertically in a circular needle bed (Hatch, 1993), as shown in Figure 2.4. The fabric formed by the needles falls into the center of the knitting machine and is collected on a roller at the bottom center of the machine.

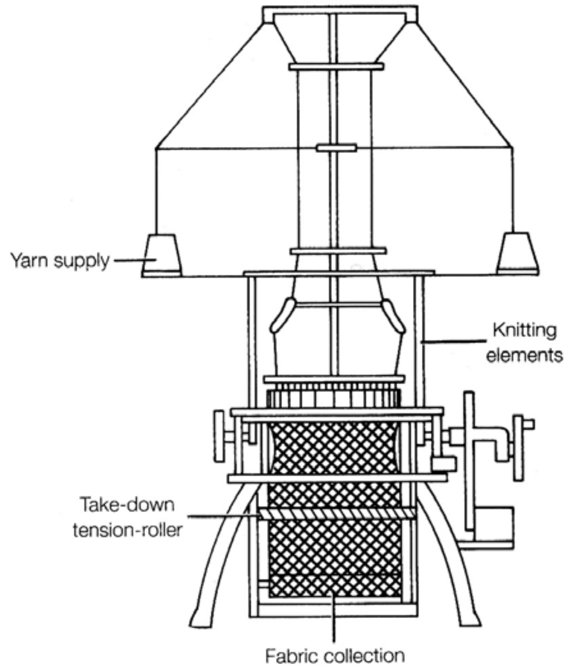


Figure 2.3: Circular jersey machine (Hatch, 1993)

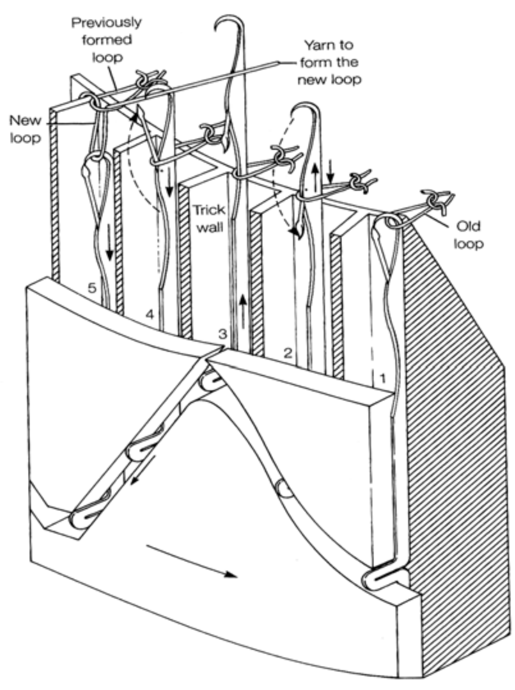


Figure 2.4: Needle arrangement for circular jersey machine (Hatch, 1993)

Rib fabric is knit on cylinder and dial machines, which utilize one set of latch needles that are arranged in two beds. Cylinder and dial machines knit a wide range of fabric structures in a variety of diameters from small 4-inch (10.16 cm) to large 36-inch (91.44 cm) diameters. The beds are positioned perpendicular to each other, as shown in Figure 2.5. The vertical latch needles located in one bed are called cylinder needles, to form knit stitches. The other set of horizontal latch needles are located in the other bed are called dial needles, to form purl stitches. Yarn is fed to the needles in the same manner as on the jersey machine. With the needles in perpendicular arrangement, the dial needles laid in the horizontal position with hooks facing upward allow loops to be pulled in the opposite direction to the vertical needles (Hatch, 1993).

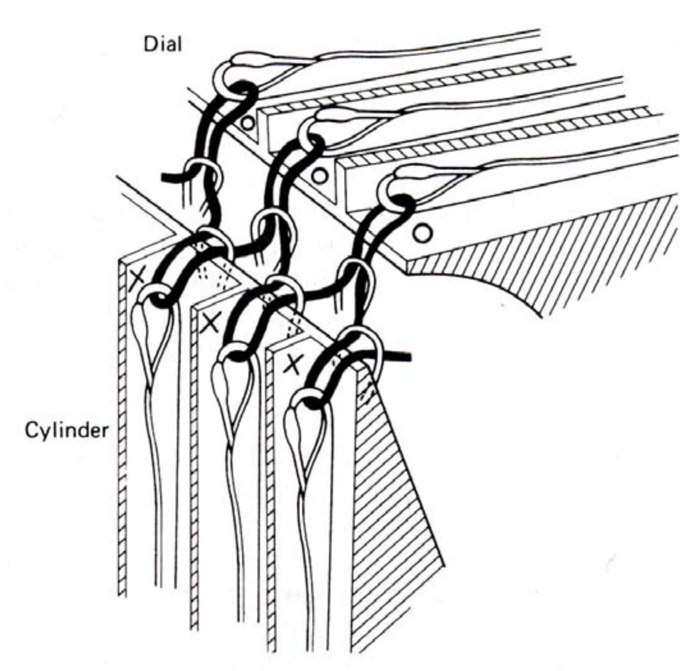


Figure 2.5: Needle arrangement on rib machine (Spencer, 2001)

The simplest purl fabrics are made on purl machines where one set of latch needles are arranged in two needle beds. There are two types of purl needle bed machines: flat bed purls and circular purls, which produce fabric in open width or tubular form, respectively. Flat bed purls have two horizontally opposed needle beds, as shown in Figure 2.6. Circular purls have two superimposed cylinders one above the other (Spencer, 2001). Spencer (2001) notes that purl machines are no longer built because electronically controlled v-bed flat machines are now able to knit types of links-links designs. In the production of the simplest purl fabric: 1x1 purl, the needles all form stitches from one bed during the first course and then transfer over to the other bed to form the purl stitches in the next course (Hatch, 1993).

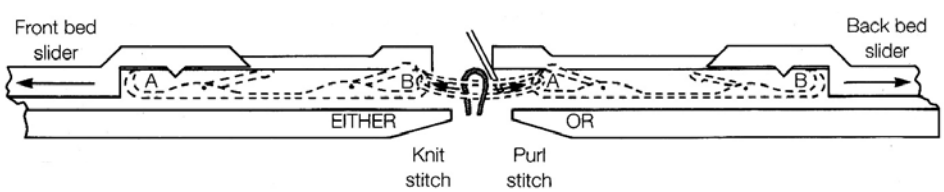


Figure 2.6: Needle arrangement on purl machine (Hatch, 1993)

In Figure 2.6, the same needle has been drawn twice to show its two possible positions in the knitting bed (Spencer, 2001)

The v-bed has the capability to produce a variety of structures, but specifically the three structures used in this research: single jersey, 1x1 rib, and moss stitch. One set of latch needles are positioned in two beds that are arranged in an inverted v formation. This type of machine produces fabric open width or tubular form. The production speed of the v-bed machine runs at slower speeds, however, the v-bed has the ability to produce complex designs that consist of different structures as well as intarsia and jacquard capabilities in producing complex color designs. As shown in Figure 2.7, a weight is used to pull the fabric down from the needles as loops are formed. In electronic knitting machines, an automated comb and takedown rollers serve the same function as a weight, but in a greater tension controlled manner.

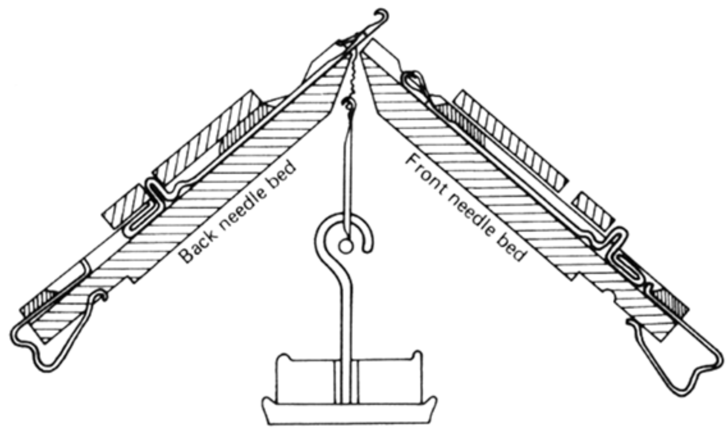


Figure 2.7: V-bed - side view (Spencer, 2001)

The v-bed is the most versatile weft knitting machine considering needle selection on one or both beds, racking, striping, changes in knitting width, loop transfer, and a wide range of counts may be knitted for each machine gauge (Spencer, 2001). The knitting action of a v-bed machine is illustrated in Figure 2.8 in four steps. According to Spencer (2001, p.212) the numbers 1 to 4 correspond to the sequence of the knitting action. Similar positions may be plotted for the return traverse.

1. *Rest position.* The basic knitting action begins with needles in rest position.
2. *Clearing.* The needles butts are lifted as they contact the leading edge of cams, which raises the needles to full clearing height.

3. *Yarn feeding.* The yarn is fed as the needles descend under the control of the cam. Each needle draws the required loop length as it descends the stitch cam.
4. *Knocking-over*. As the needle continues downward the old loop slides off the needle and the new loop is drawn through it. The continued descent of the needle draws the loop length. The distance is determined by the depth setting of the stitch cam, which can be adjusted.

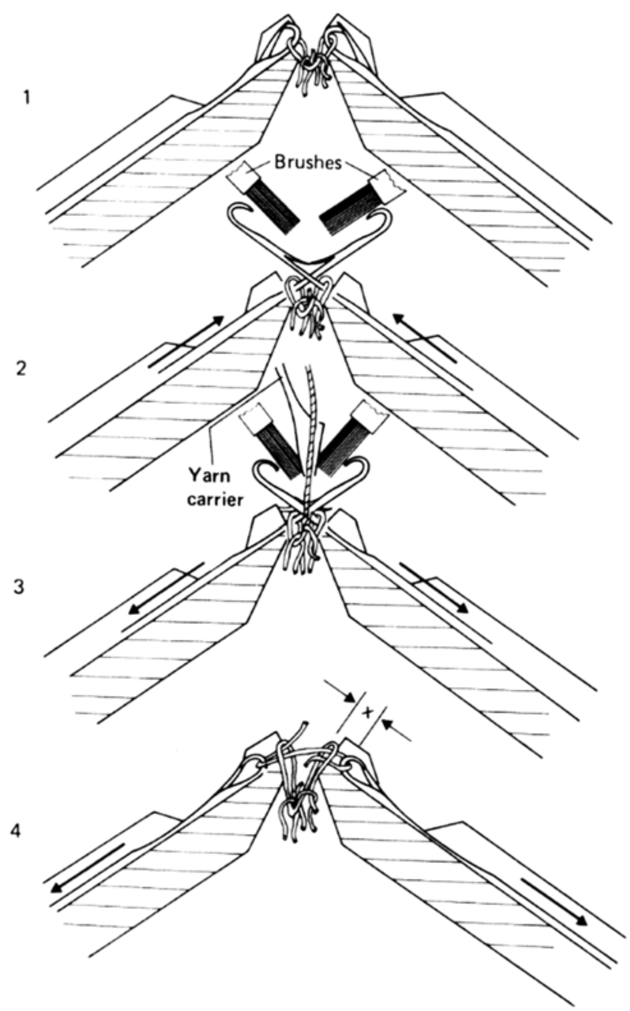


Figure 2.8: Knitting action of v-bed (Spencer, 2001)

A comparison of knitting machinery is shown in Table 2.1.

Table 2.1: A Comparison of Jersey, Cylinder & Dial, Purl, and V-bed Weft Knit Machinery (Smith, 2004)

	Jersey	Cylinder and Dial	Purl or links-links	V-bed
Speed	Fast	Fast	Fast	Slow
Fabric Cost	Least because only knitting on one set of needles	More because knitting on two sets of needles	More because knitting on two sets of needles	Most due to production time in creating complex designs.
Format	Tubular	Tubular	Open width	Open width or tubular
Sets of needles	One set	Two sets: cylinder and dial needles	Two sets: front and back needles	Two sets: front and back bed needles
Design Capability	Simple	Simple	Simple	Complex
Type of Yarns	Spun or filament	Spun or filament	Spun or filament	Spun or filament
Typical End Uses	Hosiery	Fleece	Infants' and children's wear	Sweaters

Warp knitting is accomplished by knitting loops along the length of the fabric, a series of closed loops are knitted in the lengthwise direction, as shown in Figure 2.9. There are two major classes of warp knitting machines: tricot and raschel. The tricot machine makes lightweight fabrics and is frequently used in women's items such as lingerie, swimwear, and eveningwear. Coarser yarns are generally used for raschel knitting in which the resulting knit fabric resembles hand crocheted fabrics, lace fabrics, and nettings commonly used for net curtains, table coverings, upholstery, and automobile interiors (Robinson, 1995).

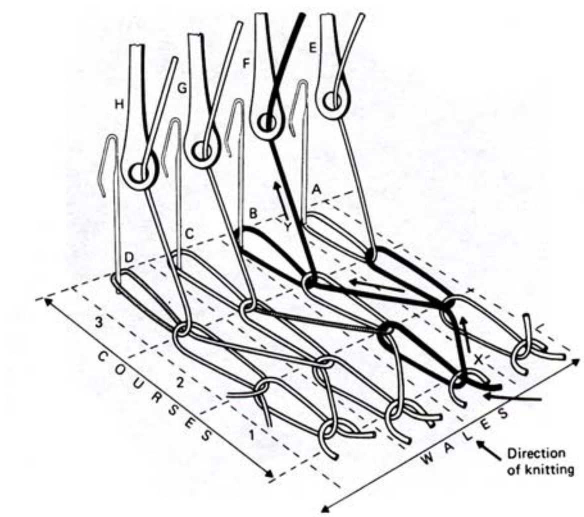


Figure 2.9: Length-wise knitting direction (Spencer, 2001)

One distinguishing characteristic that sets warp knitting machines apart from weft machines is that the yarn source derives from beams instead of yarn packages (Figure 2.10). Weft knitting technology, rather than warp technology, will be the focus of the research.

Another main difference of each machine is where the yarn supply is located. Warp beams for tricots are positioned on top and on the backside of the machine as the warp beams prevent access to the back. Warp beams for raschel knits are all positioned above the machine, which permits front and back inspection of fabric and knitting elements (Spencer, 2001).

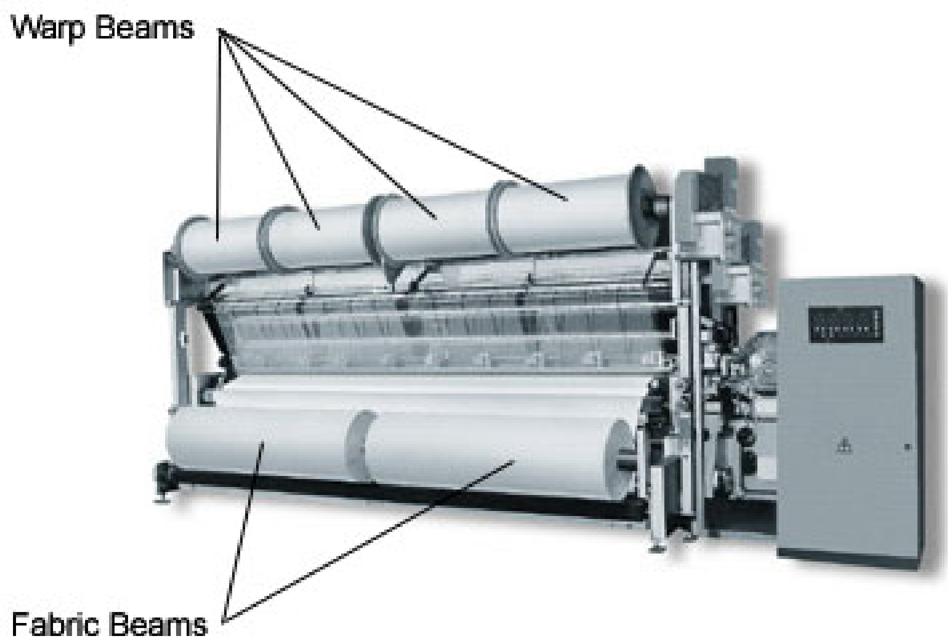


Figure 2.10: Warp knit machine (Karl Mayer, 2000)

2.2 Knit Structures

Three knit structures: single jersey, 1x1 rib, and moss stitch were chosen for investigation because they represent the basic single weft knit structure groups: jersey, rib, and purl. Single jersey fabric is used in a wide range of apparel, such as t-shirts, socks, and sweaters, due to its simplicity in needle selection and good overall stretch and recovery. Rib fabrics are mainly used in welts, cuffs, and collars for garments with plain-knitted bodies and sleeves because of its high extensibility and recovery properties. Purl fabric is widely used in children's wear because this structure is known for its benefits in length extension as the child grows.

2.3 Fabric Notations

Weft knitted fabrics may be classified into three basic groupings; jersey fabrics and derivatives, rib fabrics and derivatives, and purl fabrics and derivatives (Smith & Hudson, 1983). One structure from each of these categories will be discussed in this thesis: plain single jersey, 1x1 rib, and a purl structure known as the moss stitch. There are two types of weft knit notations used: diagrammatic and graphical.

2.3.1 Fabric Notations for Single Jersey, 1x1 Rib, and Moss Stitch

Graphical and diagrammatic notations are used to communicate knit structure (Table 2.2). Diagrammatic and graphical notation examples are provided in the following section for the structures that are the focus of this research.

Table 2.2: Weft Knit Notations (Smith, 2004)

1. Diagrammatic	• Lines represent the path of the yarn as it knits
	• Dots represent the needles
	• Numbers represent the courses and their sequence
	• Arrangement of needles illustrates the gaiting
	    • Head to head is known as interlock gaiting
	    • Alternate needle arrangement is know as rib gaiting

2. Graphical	• Fabrics are represented by pictures or drawings • Usually only one side of the fabric is shown • Good for illustration but details are hidden or unknown

3. Symbolic	• Utilizes symbols to indicate the type of loop X front loop • tuck loop o back loop □ float

In Figure 2.11, the single jersey structure shows two courses and three wales. All loops are knitted on the front bed, therefore only the front bed needles are utilized. The graphical illustration in Figure 2.12 shows the knit loop appearance of single jersey in fabric form.

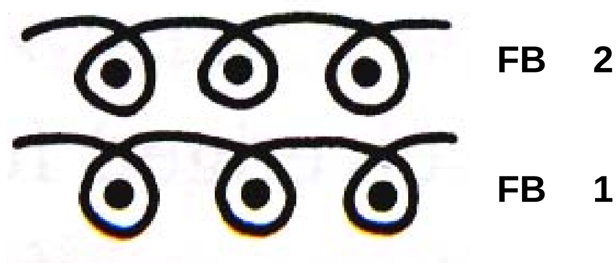


Figure 2.11: Single jersey, diagrammatic (Spencer, 2001)

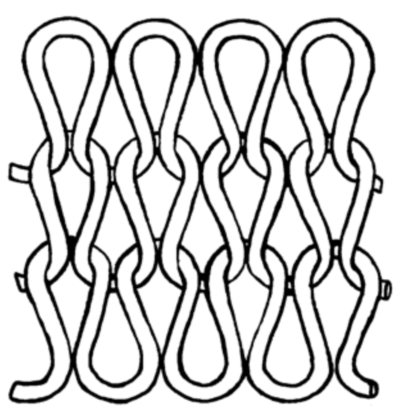


Figure 2.12: Single jersey, graphical (Shinn, 1957)

The 1x1 rib structure is represented in Figure 2.13 in two courses and two wales. The needles are arranged in rib gaiting position, which indicates that the front and back beds are utilized in producing the 1x1 rib. The yarn path indicates that the course loops are knitted starting from the front bed needle to the back bed needle. Each wale knits on the front needle then to the back needle. The graphical illustration in Figure 2.14 shows the knit loop appearance of 1x1 rib fabric form.

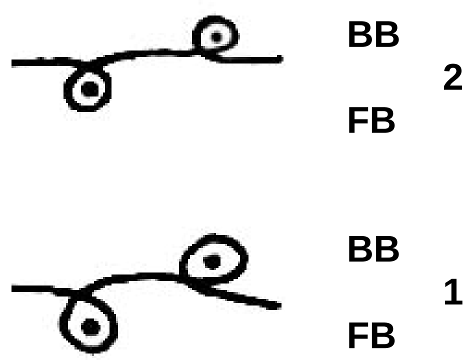


Figure 2.13: 1x1 Rib, diagrammatic (Spencer, 2001)

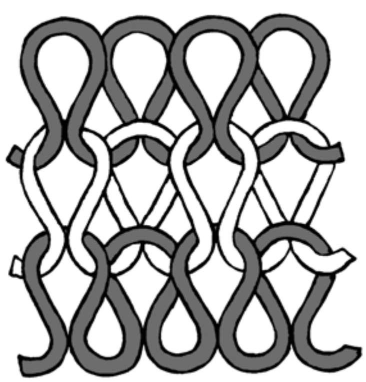


Figure 2.14: 1x1 Rib, graphical (Shinn, 1957)

The moss stitch is represented in Figure 2.15 in two courses and two wales, where both front and back beds are utilized. The course loops are knit from front needle to back needles each time, but wale loops alternate from the front needle to back needle within each course. The moss stitch is a variation of the classic 1x1 purl represented in Figure 2.16. The 1x1 purl differs from the moss stitch investigated here in that the moss stitch consists of face and reverse loops in alternate courses and wales while the classic 1x1 purl consists of face and reverse loops only in alternate courses.

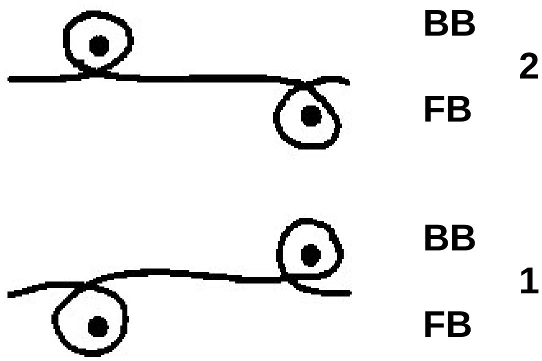


Figure 2.15: Moss Stitch, diagrammatic (Spencer, 2001)

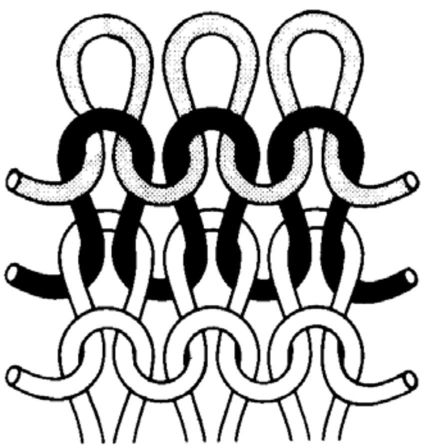


Figure 2.16: Classic 1x1 Purl, graphical (Shinn, 1957)

The three structures selected for investigation are commonly used in the knitting industry because they each have characteristics that make them useful in various applications. A comparison of the structure properties and potential problems of single jersey, 1x1 rib, and moss stitch are shown in Table 2.3.

Table 2.3: A Comparison of Single Jersey, 1x1 Rib, and Moss Stitch (Smith 2004)

Structure	**Single Jersey**	**1x1 Rib**	**Moss Stitch**
Appearance	Loops on face	Both sides identical	Both sides identical
Extensibility- width	Less than 1x1 rib and moss stitch	High	Similar to single jersey
Extensibility- length	Medium	Less than single jersey and moss stitch	High- twice that of single jersey
Format	Tubular or open	Tubular or open	Open
Needle setup	Front bed needles	Rib gaiting, front and back beds used	Front and back beds used
Stability	Instable	Stable	Stable
Potential Problems	**Single Jersey**	**1x1 Rib**	**Moss Stitch**
Bowing	Due to structural instability	Due to ease of width extension	No bowing due to stable structure
Bias/skew	Inherent course bias so usually fabric is finished tubular	Not a problem when using small number of feeders	No bias/skew due to stability
Spirality- wale	Due to inherent structural imbalance	Not a problem because structure is balanced	Not a problem because structure is balanced
Curl	Curling due to unbalanced structure	No curling due to balanced structure	No curling due to balanced structure
Shrinkage	Differential shrinkage due to bias	High and variable width shrinkage due to ease of distortion	Mostly in length
Width	All knit loops on face preserve finished width	Fabric finishes narrow	Alternating loops for every wale and course preserve finished width

2.3.2 Single Jersey Characteristics

Plain structure or single jersey is the simplest weft knit structure. The single jersey structure is composed solely of knit loops knitted on one bed of needles, as shown in Figure 2.17. Its production rate is very high because of stitch simplicity, and it is relatively inexpensive to produce because of machine simplicity (Smith, 2004).

FB 1

Figure 2.17: Single Jersey (Spencer, 2001)

This fabric is unbalanced because it is knitted on one set of needles, therefore the loops tend to curl towards the front at the top and bottom ends and towards back at the sides, which makes curling difficult to control (Ajgaonkar, 1973). Spirality and bias are common problems in single jersey due to its inherent structural imbalance (Smith, 1983a). The spirality and bias of single jersey occurs when the wales and courses lean. The effects of spirality results from yarn twist (Lau, 1995). This causes the fabric to be bent easily uninhibited by its simple structure.

Jersey fabrics are commonly used in the production of hosiery, socks, t-shirts, and underwear. Hatch (1993) states that jersey fabrics have good crosswise and lengthwise elongation, and the degree of elastic recovery varies with the fiber content and yarn structure. The fabric properties and parameters of a jersey structure are also dependent on the loop length (Ajgaonkar, 1973). Demiroz and Diaz (2000) determined the relationship between loop length and fabric deformation by experimenting with a series of plain-knit structures produced on a v-bed machine.

They noted that a deformed and non-uniform loop shape was most visible in loose constructions or high course lengths. For quality knitting, all loops must be uniform in size and appearance (Shinn, 1976) ensuring consistent performance throughout the fabric.

2.3.3 1x1 Rib Characteristics

The most important property of rib fabric is its ability to stretch (Shinn, 1976). The 1x1 rib knit structure is known for its high width-wise extensibility and recovery. The ease of bending wales in a 1x1 rib results largely from high width extensibility. There is no spirality in the structure; however minimal skew is enough to easily distort the fabric (Smith, 1983b). Two sets of needles are used in forming a 1x1 rib, producing a balanced fabric with identical loops on both sides, as shown in Figure 2.18.

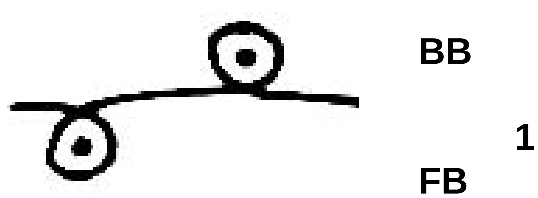


Figure 2.18: 1x1 Rib (Spencer, 2001)

The two sets of needles are gaited or arranged so the front bed needles are offset from the back bed needles. This needle arrangement causes the face wales to move over and in front of the reverse wales, as shown in Figure 2.19. This rib gaiting contributes to fabric thickness, fabric width, instability and resilience (Smirfitt, 1965b).

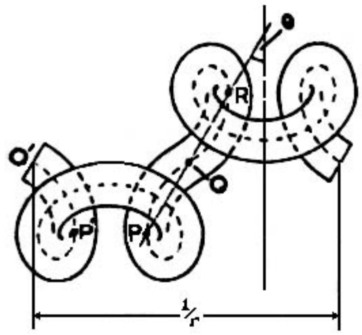


Figure 2.19: 1x1 Rib - perspective view (Smirfitt, 1965a)

Although knitted rib structures are widely used in outerwear, their main use is in providing welts, cuffs, and collars for garments with plain-knitted bodies and sleeves. There are two properties of 1x1 rib fabric that make it particularly suitable for these trimmings. First, fabrics of this type are free from edge curling because they are balanced, unlike the unbalanced structure of single jersey that causes edges to curl. Secondly, rib fabrics readily extend in width and show immediate recovery from extension (Smirfitt, 1965b).

2.3.4 1x1 Purl and Moss Stitch Characteristics

The 1x1 purl is a basic purl stitch. Purl fabrics by definition are the only knit fabrics that alternate loops within a course from the face to the rear. In the classic 1x1 purl there is one course of face loops followed by one course of rear loops (Smith, 2004). The purl structure selected for this research is a simple purl structure called the Moss Stitch, not the traditional 1x1 purl structure. The moss stitch can be used to create stability in a fabric because it consists of face and reverse loops in alternate courses and wales, as shown in Figure 2.20, and produces a relatively compact fabric.

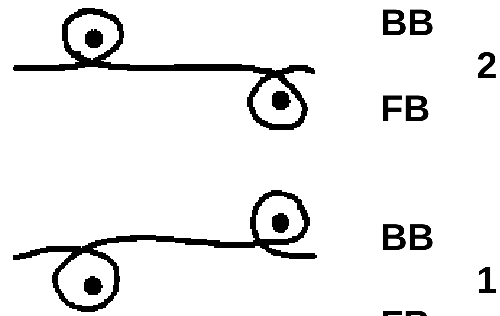


Figure 2.20: Moss Stitch (Spencer, 2001)

The moss stitch structure yields a stable fabric with identical loops on both sides. The purling action, when relaxed, causes the face loop courses to cover the reverse loop courses, making the fabric twice as thick as single jersey (Spencer, 2001). The moss stitch is expected to produce a very stable knitted structure because of its balanced structure.

Purl fabric is an important weft knitted structure widely used with other structures as a fabric design element (Kurbak, 1995). Purl fabrics are also known for lengthwise and widthwise recovery. The characteristics of the 1x1 purl structure suggest that the majority of extension will occur in the length direction. This is due to the distance between the front and back bed, which creates space for loop extension.

2.4 Structural Issues Related to Single Jersey, 1x1 Rib, and Moss Stitch Fabrics

There are two major problems of structural instability associated with single jersey: spirality and bias (Table 2.4). These contribute to stabilization issues when the fabric distorts as it relaxes. Plain weft fabric or single jersey is composed of a series of courses. Each course is intermeshed with both the preceding and succeeding courses. The continuation of this repeat for every course and wale makes this an unbalanced fabric because all loops are constructed with front bed needles on a v-bed machine.

Table 2.4: Structural Issues of Single Jersey, 1x1 Rib, and Moss Stitch

	Single Jersey	**1x1 Rib**	**Moss Stitch**
Curling	Occurs because fabric is unbalanced, loops only on one side	None because the fabric is balanced	None because the fabric is balanced
Shrinkage	Occurs due to fabric simplicity of consisting only face loops	High width shrinkage occurs due to ease of distortion	None because alternating loops in course and wales preserve width
Pilling	Occurs when spun yarns are used	Occurs when spun yarns are used	Occurs when spun yarns are used
Spirality	Occurs when fabric is allowed to relax, not present when fabric is on the machine	None because there are wales on both sides	None because there are wales on both sides
Bias	Occurs when fabric is allowed to relax, not present when fabric is on the machine	None because only one feed is used	None because only one feed is used

This inherent structural imbalance causes spirality and bias. Spirality refers to wales and bias refers to courses. Bias occurs when courses do not knit horizontally in the fabric but rather on an incline. The degree of wale spirality is associated with the level of yarn twist (Smith & Hudson, 1983) and has obvious influence on both the aesthetic and functional performance of knitwear (Chen, 2003). For example, if high twist yarn is used, usually a spirality of wale lines occurs. This unstable configuration of a plain knitted loop is considered to be one of the drawbacks of plain knitted structures (Ajgaonkar, 1973). Once a single jersey fabric is allowed to relax, the simplicity of the structure permits spirality and bias to become more apparent and more influential on structural interactions (Smith, 2004).

Smith and Hudson (1983) explain that the 1x1 rib stitch (Table 2.4) comprises two plain-type face loops meshed in opposite directions and linked by short lengths of yarn, which pass through the fabric. In 1x1 rib there is one wale on the technical face of the fabric followed by one wale on the technical rear. Because there are loops formed on both sides of rib structures, these constructions are generally more stable and more expensive than single jersey fabrics. In fabric form, the rear wales do not appear unless the fabric is extended in width. The rear wales can be seen as a vertical trough that appears on the technical face perpendicular to the courses (Smith & Hudson, 1983).

Purl fabrics are also referred to as *links-links* fabric. The purl stitch forms a rib effect alternating in courses to produce links-links fabric with horizontal ridges showing on both sides (Leary, 1986), however, the moss stitch (Table 2.4) does not share these characteristics due to its structure.

The minimum energy state, which describes a fabric when it reaches its ideal relaxed state, is different for every knit structure. Therefore, we can expect some sort of fabric deformation, such as arcing, to occur when two structures are joined side-by-side. There is contention that adjoining structures will produce interactions, such as arcing, when different structures are combined. For example, figures 2.21 and 2.22 illustrate two different weft knit structures, half cardigan and full cardigan, respectively. Figure 2.23 illustrates half cardigan and full cardigan joined side-by-side to demonstrate the loop interaction when the two structures are knitted together. Similarly, distortions can be expected if single jersey is knitted beside an unstable fabric like 1x1 rib. If single jersey is knitted beside a stable fabric such as moss, there potentially could be substantial jersey distortion.

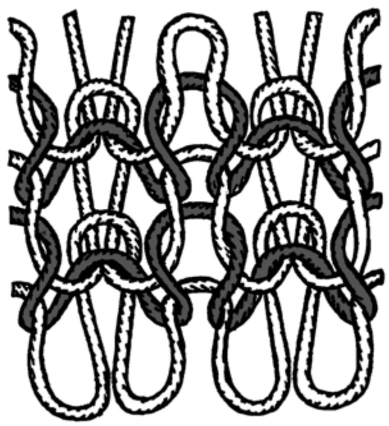


Figure 2.21: Half Cardigan (Shinn, 1957)

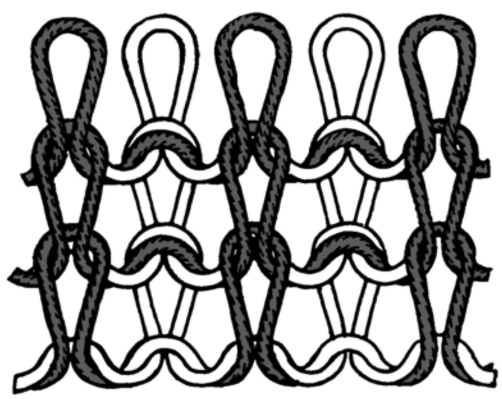


Figure 2.22: Full Cardigan (Shinn, 1957)

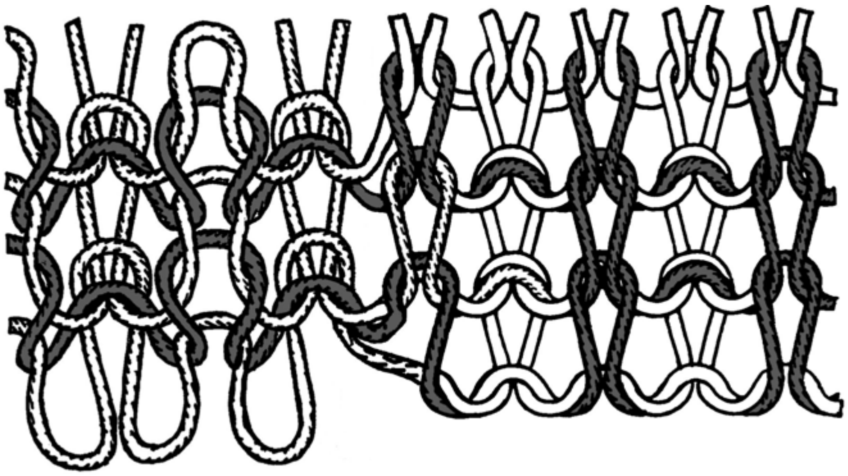


Figure 2.23: Half and Full Cardigan adjoined

2.5 Loop Length and Tightness Factor Control

The fabric properties and parameters of a knitted structure are dependent on the loop length. When loop length is reduced, the fabric may appear tight and rigid, so as the loop length increases, the fabric may appear looser and less rigid (Ajgaonkar, 1973). Loosely knitted fabrics are easily extensible and distorted; where as tightly knitted fabrics are more stable and less susceptible to distortions. Changes in loop length will cause an increase or decrease in the weight per unit area, which influences cost. Increasing the loop length will cause a decrease in the weight per unit area. This decrease in weight is due to the reduction in the number of courses per inch by lengthening the loop so that the length of yarn in a course was increased. Shortening the loop will have the opposite effect (Shinn, 1955). Figure 2.24 illustrates how yarn size affects the tightness of a fabric. Tightness is represented by the ratio d/l, where d is yarn diameter and l is the length of yarn in a loop (Hepworth, 1982). Munden (Spencer, 2001) suggested the use of a factor to indicate the relative tightness or looseness of plain weft knitted structure. Tightness factor can be calculated by using the formula $K = \sqrt{Tex} / L$ where Tex is the yarn linear density and L is loop length in centimeters. The fabric dimensions depend on the tightness of the fabric. In fabrics knitted with the same loop length, the fabric dimensions vary with the count of the yarn (Hepworth, 1982).

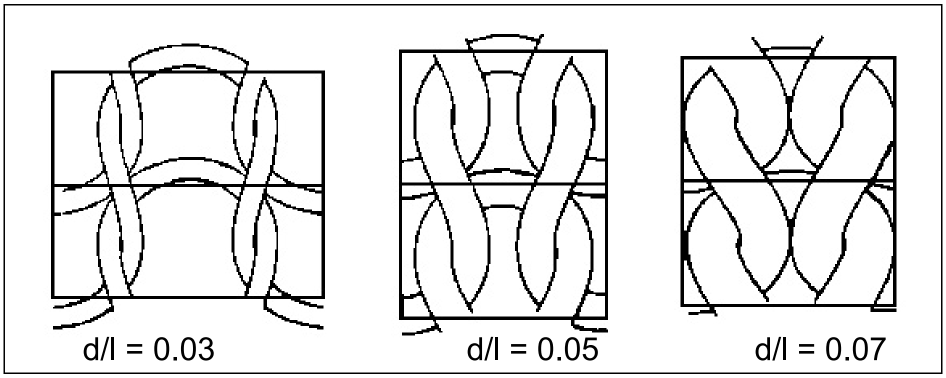


Figure 2.24: Effect of yarn size on tightness (Hepworth, 1982)

The fabric dimensions associated with these loop shapes are represented by the rectangles that are unit cells of fabric. Hepworth (1982) uses these extreme examples of the single jersey structure to show clearly the differences in shape of both the loops and the unit cells. They were also chosen to illustrate the different states of *jamming* that can occur in relaxed fabrics. The term "jamming," a phrase coined by Hepworth (1982), occurs when courses or wales apply pressure at contact points. In Figure 2.24, it was determined that courses jam for $d/l > 0.031$, except for very slack fabrics. In addition there is jamming between wales in tight fabrics for which $d/l > 0.06$ (Hepworth, 1982). Jamming will produce a more rigid fabric than a fabric with less jamming. Therefore, fabric distortions are expected to occur in fabrics with less jamming or a low K value.

2.6 Influence of Loop Length on Fabric Characteristics

Changes in loop length will cause an increase or decrease in the weight per unit area (Shinn, 1955). Producing fabric with varying weight in this way may influence cost due to the amount of yarn consumed in fabric production and also influence fabric performance characteristics. Knit fabrics can be knitted loosely or tightly, but normally are knitted somewhere around the middle tightness depending on the end use of the product and the desired aesthetics. For example, hosiery should be knit tight enough to form fit the body and remain taut during movement and extended wear, but loose enough for comfort and appropriate fit. Each fabric has different extremes of knit tightness also dependent on the end use.

In terms of distortion, greater fabric distortion is expected in looser fabric (Smith & Hudson, 1983). Spirality and bias in single jersey cause fabric distortion, which is more apparent in loose knits. Wales should be completely vertical but spirality and extraneous forces can deform them.

2.7 Effect of Yarn Size and Knit Structure on Fabric Thickness

Yarn size and volume can potentially have a direct influence on the amount of fabric thickness and resilience. If equal loop lengths are used, a yarn with a larger diameter, such as a bulkier yarn, would effectively make the fabric tighter which could in turn influence the amount of fabric movement due to less open space in the fabric. In Figure 2.25, for each loop, the loop length is the same, and the diameter of the yarn is varied.

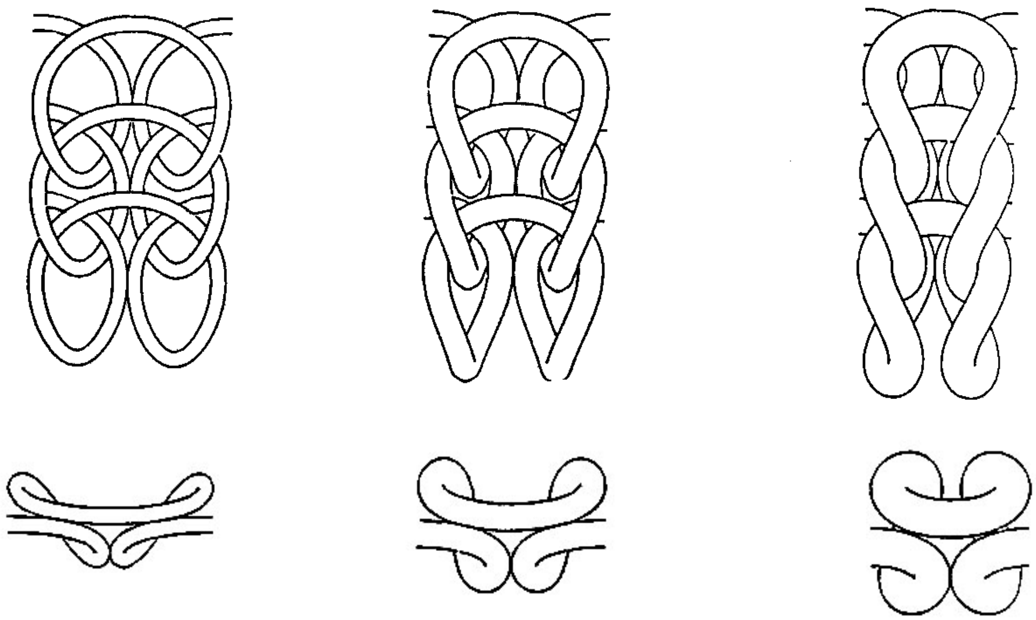


Figure 2.25: Yarn size influences on fabric tightness and thickness- perspective view (Hepworth, 1989)

Additionally, if a bulky yarn were used to knit two structures, single jersey and 1x1 rib side-by-side, the single jersey side would be thinner than the 1x1 rib side. This is because of the difference in loop interaction of knitting on one set of needles versus knitting on two sets of needles. If 1x1 rib and moss stitch were knitted side-by-side, the 1x1 rib fabric would be thicker than the moss stitch side of the fabric. The thickness of the rib is attributable to needle arrangement.

2.8 Spun and Filament Yarn

The type of yarn used can influence the desired fabric characteristics such as fabric comfort, strength, and luster. Spun yarns are composed of staple fibers held together by some binding mechanism (Hatch, 1993). There are three types: ring spun, open-end, and air-jet. There are several distinctions between the three types of spun yarns, such as the positioning of the staple fibers and the binding mechanism. For instance, in ring spun wool yarns, the degree to which the fibers lie parallel to the axis of the yarn is impacted by whether the yarns are woolen or worsted. Woolen yarns contain shorter fibers that are less aligned than the longer fibers in worsted yarns, as shown in Figure 2.26. According to Hatch (1993), the word *worsted* can be used to describe 100% manufactured-fiber spun yarns. For example, a yarn package of acrylic may read *100% worsted acrylic*, indicating that the acrylic fibers are approximately the same length as wool fibers in worsted wool yarns. Woolen yarns have more protruding fiber ends, which make the yarn fuzzier and have less even diameters. The composition of protruding fibers creates open space between loops in the fabric.

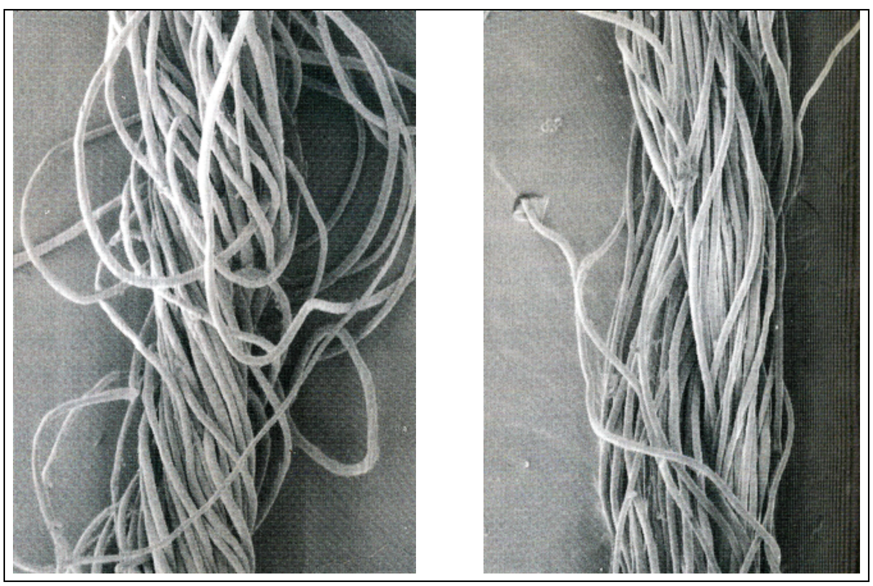
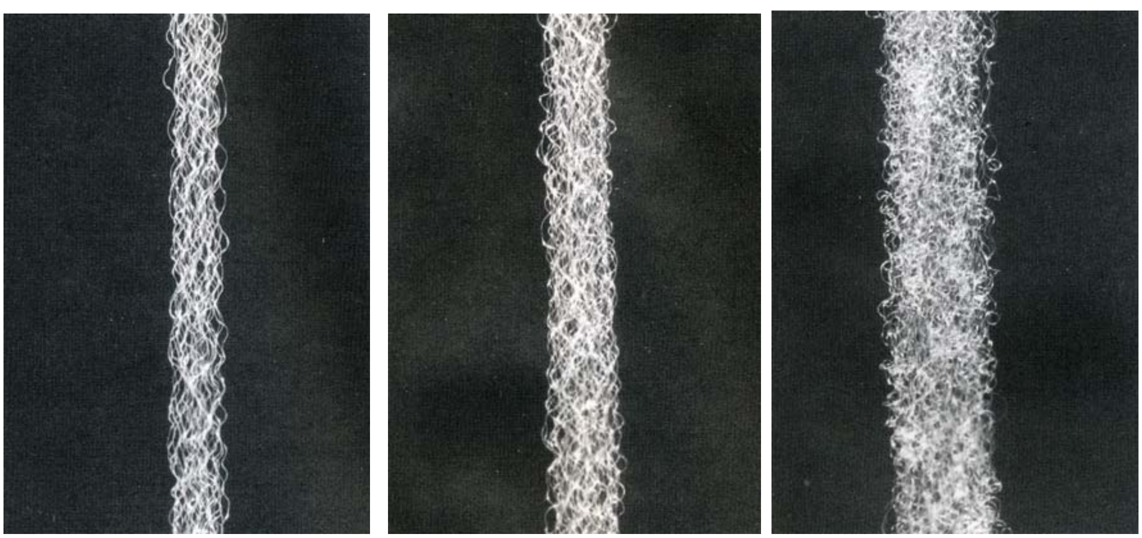


Figure 2.26: Woolen (left) and worsted (right) ring spun yarn (Hatch, 1993)

Filament yarns are composed of continuous filaments assembled with or without twist (Hatch, 1993) and may be textured and bulked. Textured yarns have noticeably greater apparent volume than an untextured yarn of similar filament count and linear density. The amount of volume and bulk in a filament yarn is less than in a spun yarn; however, the number of filaments can influence the fullness of the yarn as shown in Figure 2.27. It is apparent that as the number of filaments increases the yarn diameter increases. The microfilament yarn has twice the bulk and surface area of the standard filament yarn because the microfilament yarn contains about four times as many single filaments as the standard yarn (Hatch, 1993). The use of microfilament yarn can alter the performance and aesthetics of the fabric in comparison to the standard yarn. Hatch (1993) further explains that the greater number of filaments in yarns of identical linear density, the softer and more easily bent the yarn becomes.



Standard dpf yarn, 100/36 dtex

Fine dpf yarn, 100/72 dtex

Microfilament yarn, 100/144 dtex

Figure 2.27: Number of filaments (Hatch, 1993)

Spun and filament yarns have considerable differences in performance, comfort, and aesthetics. Spun yarns are weaker than filament yarns of the same size and fiber type. The strength of spun yarns primarily comes from the ability of the fibers to adhere to each other, within the yarn twist. Filament yarns get their strength from their length and surrounding filaments because each filament spans the length of the yarn (Hatch, 1993).

Comfort differs in fabric made from spun and filament yarns. Spun-yarn fabric is more absorbent than filament-yarn fabric of the same fiber content and yarn size because the fibers are less packed in spun yarns. More surface area is available for water absorption in spun yarns. Spun-yarn fabrics also have higher insulative capability and water vapor permeability because there is more space between the fibers than between filaments in filament yarn. Spun-yarn fabric feels warmer than filament-yarn fabric because the protruding fibers of the spun yarn hold the body of the fabric above the surface of the skin. This establishes a thin air layer between the skin surface and inner fabric surface (Hatch, 1993).

Aesthetics of spun-yarn fabrics and filament-yarn fabrics differ greatly. Spun yarns are bulky and have fuller appearance. Spun-yarn fabrics are usually softer, less lustrous, and have higher covering power than filament-yarn fabrics. There is essentially more rigidity in spun yarn and they tend not to slip in fabric because they are not as slick as filament yarns. As fabrics are worn, those made of spun yarns initially perform better than filament-yarn fabrics because they retain their cross-sectional shape better under various compressional and bending deformations (Hatch, 1993). In spun yarns, the combination of having long and short fibers induces fabric pilling. Pilling occurs when broken fibers migrate to the external parts of yarns, so that fuzz emerges on the fabric surface. Due to friction, this fuzz gets entangled, forming pills that remain suspended from the fabric by long fibers (Xin, 2002). Ceken (2000) determined that densely knitted single jersey fabric resisted pilling better than loosely knitted single jersey fabrics. The denser fabric construction holds fibers tightly in place while reducing the number of migrating fibers.

Filaments are assembled with or without twist. Textured and bulk yarns are made to have greater covering power and volume than a yarn of equal linear density and the same basic material with normal twist. The filaments in textured and bulked yarns lie greater distances apart and are more randomly distributed than in flat yarns (Hatch, 1993).

The texturing and bulking process is applied to impart fabric comfort and aesthetics to the end product. The air space between the filaments allows air and moisture permeability of the fabric. For example, in still air, air is trapped within the textured yarns, enhancing the thermal insulative ability of the fabric. In a breeze, the open fabric permits the movement of body-heated air away from the body surface, and cooling results. Texturing also enhances body-movement comfort. Fabric made from these yarns elongates more, therefore allowing the wearer a greater freedom of movement (Hatch, 1993).

2.9 Fiber Type

Acrylic is a synthetic fiber, which is crimped to achieve the soft quality. Therefore, the acrylic fibers do not pack together tightly in yarn or fabric form. Because the fibers create a full yarn, they can restrict loop movement in fabric form. An example of fiber bulking is shown in Figure 2.28, with the use of regular- and latent-shrinkage acrylic fibers in preparing a bulk yarn. Bulk may also result from a single fiber itself.

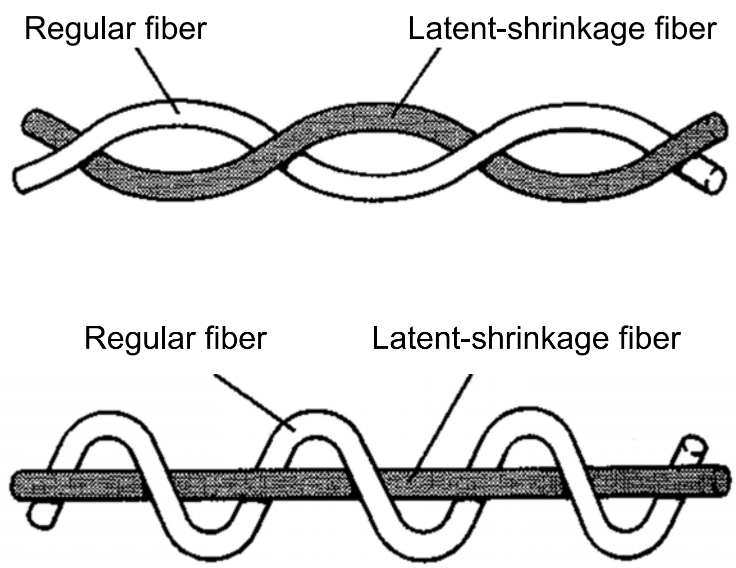


Figure 2.28: Bulking of acrylic fibers (Hatch, 1993)

For example, the wool fiber is a natural fiber and consists of high volume and bulk. A wool fiber is crimped three-dimensionally as shown in Figure 2.29. The cortex is illustrated, the core of the wool fiber, which forms about 90% of the fiber volume (Hatch, 1993). Hatch (1993) explains that the cortex is divided into two distinct sections, the orthocortex and the paracortex. These sections spiral around each other along the fiber length, which explains the three-dimensional crimp.

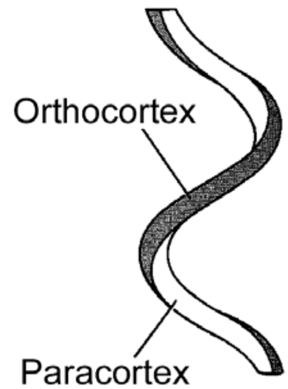


Figure 2.29: Submicroscopic structure of wool fiber (Hatch, 1993)

This three-dimensional crimp creates yarn volume and bulk and prevents the loop movement in the fabric. However, the bulk of the yarn can be compressed or released by surrounding loops. This action is influenced by the fabric tightness.

Polyester and polypropylene are both synthetic filaments. Characteristic of synthetic fibers, filaments can be textured to create yarn bulk (Figure 2.30).

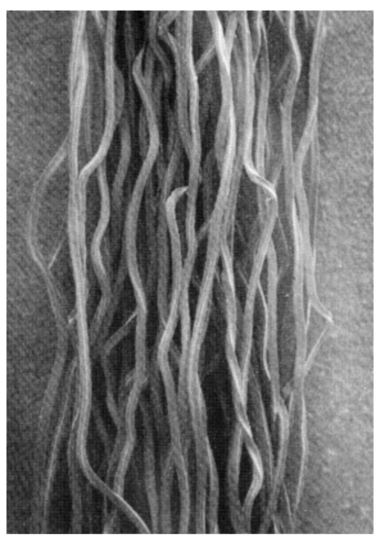


Figure 2.30: Textured filaments (Hatch, 1993)

2.10 Fiber Properties and Influences

Differences in the specific gravity values of fibers influence the ultimate weight of a fabric (Hatch, 1993). Specific gravity is the ratio of mass of fiber to the mass of an equal volume of water at 4°C. Figure 2.31 depicts the minimum specific gravity values for four fiber types listed from lowest to highest values. The range of values is as followed: olefin (0.90 - 0.92), acrylic (1.12 – 1.19), wool (1.15 – 1.30), and polyester (1.23 – 1.38).

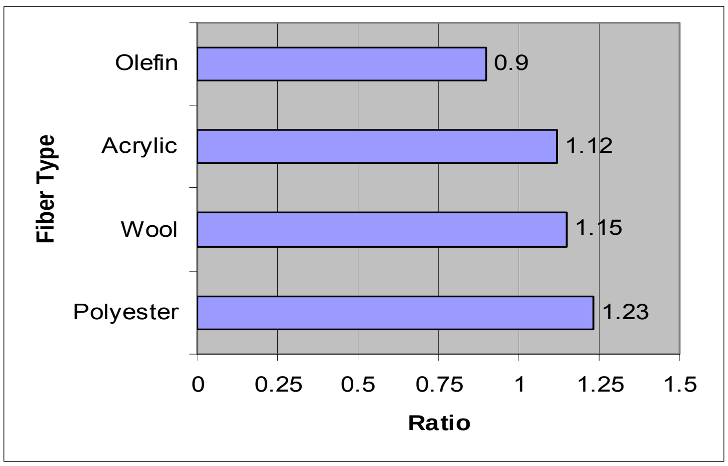


Figure 2.31: Specific Gravity (Hatch, 1993)

For example, the overall weight of an acrylic fabric is expected to be heavier than a an olefin fabric that consists of a lower specific gravity value. When a high volume, acrylic fiber is knitted in a loop it will create less open space due to the volume of the spun yarn. Therefore, the resulting fabric will be less prone to deformation since loops have a limited space to move around. In terms of tightness factor, this fabric would have a greater tightness factor (small tightness factor [K] value) compared to a fabric knitted with a filament yarn given the yarn count is equal for both yarns.

2.11 Minimum Energy State

A stable state of a fabric is defined by Munden as being one of minimum energy: that is, if the dimensions of the fabric are changed from the stable condition, the fabric will, of its own accord, return to the same stable dimensions. It was also stated that this ideal state in knitted fabrics are difficult to recognize and to achieve (Recent, 1969, p. 5). The relaxed dimensions of any knitted structure are of interest because, by whichever method the fabric is produced, some distortion is introduced into the fabric on the machine (Hepworth, 1989). According to Munden (1959), after knitting, the yarn that was originally straight desires to return to the straight state but is prevented from doing so by equal and opposite reactions from the interlocking yarns. For any one loop or row of loops to straighten, a greater bending is necessary in neighboring loops or rows of loops to accommodate this change. So the whole structure tends to go into a state of minimum energy. This is basically the mechanism of relaxation.

2.12 Concept of Relaxed States

The process of dimensional change of a fabric towards a stable state from a distorted state or from one stable state to another stable state is called relaxation (Recent, 1969, p.7). According to the Wool Science Review (Recent, 1969), there are several relaxed states of knitted fabric, three of which are given below: dry-relaxed, wet-relaxed, and fully-relaxed, as shown in Figure 2.32. The dry relaxed state occurs when the fabric has been taken off the knitting machine and in time attains a dimensionally stable condition. The wet-relaxed state occurs if the fabric is soaked in water and allowed to dry flat to reach a dimensionally stable condition. The fully relaxed state is reached when the fabric is subjected to agitation in water or steam and tumble dried at 70°C for one half hour to one hour resulting in denser fabric.

After leaving the machine, fabric dimensions change until a stable condition is reached and where no external forces act on the fabric (Hepworth, 1989). As a fabric undergoes dry relaxation, the course length recovers a certain percentage depending on yarn type. Plain knit wool fabrics may be expected to return to their strain-free condition if allowed to relax freely, but the recovery for cotton fabrics will never be complete (Munden, 1959, p. T450). A single jersey fabric knitted from a worsted yarn will recover from a 60-80% extension in length to its natural length after 48 hours if allowed to relax freely in the dry state (Munden, 1959, p. T450). In general, dry relaxation may result in narrower widths and shorter lengths of fabric because loops are drawn inwards as they reach the relaxed state.

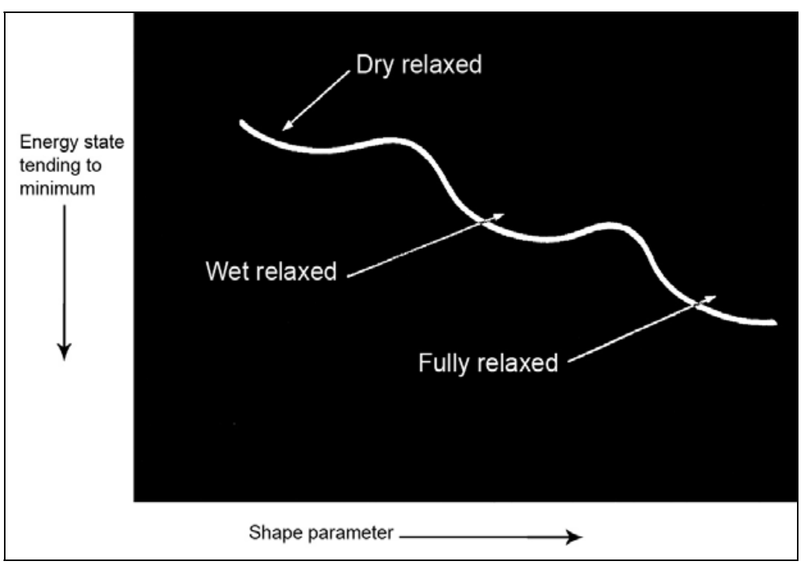


Figure 2.32: Relaxed states (Recent, 1969)

In Figure 2.32, the long shallow troughs indicate that the various relaxed states are imprecisely defined, due mainly to the mechanical properties of the fibers and the inter-yarn friction restricting free movement (Recent, 1969). Fabric dimensions are expected to occur in one-structure fabric when the fabric is allowed to sit as it reaches the dry relaxed state. Therefore, the occurrence of dimensional change in two-structure fabrics is expected.

2.13 Machine State vs. Structural Characteristics

The machine state of the fabric occurs when all wales and courses are completely vertical and horizontal. Distortions can be recognized when the fabric is altered from the machine state. With the use of spun yarns, one can expect more redistribution of stresses in the fabric due to the spirality or untwisting action of the yarn. Filaments do not have this tendency because the level of twist applied is not enough to affect distortion. The untwisting action of spun yarns may give a small amount of distortion in the fabric. Therefore, fabric spirality is minor when one yarn feeder is used. Alternatively, a multifeed cylinder machine would have more problems, than a single feed machine, with spirality and bias depending on the structure (Smith, 2004).

In single jersey, spirality and bias are present; however minimal bias is present in 1x1 rib fabric. In purl fabric, there is no problem with spirality or bias. Distortions such as spirality and bias become more apparent as a fabric relaxes because loops are able to shift easily. Therefore structure interactions are expected when two different structures are joined together depending on fabric tightness and structure-to-structure relationships.

2.14 Fabric Deformations

Fabric deformations such as arcing can be considered positive or negative effects depending on the desired aesthetics and function of the end product. The fabric is considered deformed when it is altered from its machine state (Figure 2.33). Fabric distortions are more pronounced in loosely constructed fabric (Smith & Hudson, 1983). The images in this section are of knitted fabrics with a grid design.

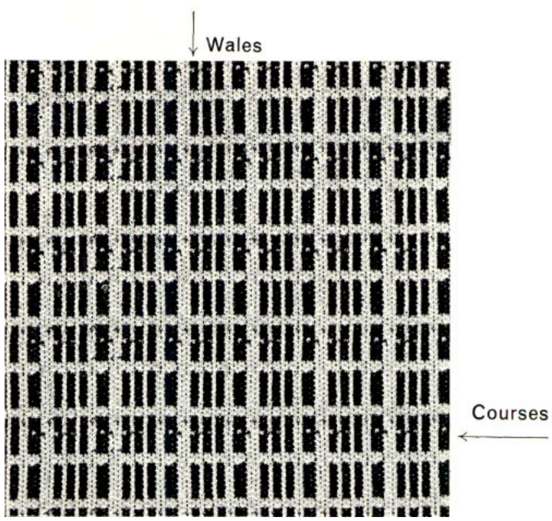


Figure 2.33: Machine state (Stacey, 1971)

Stacey (1971) defines the deformations listed in Table 2.5 as negative aspects of fabric. Stacey (1971) uses the term bowing which means the bending of courses; however in this experiment the deformation of arcing is the focus, which refers to the bending of wales. These deformations are introduced into fabrics during the knitting process and directed only to single structured knits. They may be caused by worn needle elements, uneven takedown tension and uneven fabric level in takedown rollers among other knitting elements. Takedown rollers provide even takedown tension on the fabric (Shima Seiki, 2004). Deformations of some type may also be expected when two different knit structures are joined together. Therefore, instead of machine-induced deformations, structure-induced deformations may occur.

Table 2.5: Fabric Deformations (Stacey, 1971)

Bowing	Forward	Courses in upward direction
	Backward	Courses in downward direction
	Compound	Courses in upward and downward direction
Skewed courses*	S	Courses are skewed in “S” direction
	Z	Courses are skewed in “Z” direction
Skewed wales*	S	Wales are skewed in “S” direction
	Z	Wales are skewed in “Z” direction
Banana		Wales are curved and courses are not parallel to one another

*The term skew denotes distortion for both course and wale directions, but more specifically skew refers to courses and spirality refers to wales.

Bowing occurs when courses are deformed to form forward, backward or compound curves (Figures 2.34, 2.35, 2.36). Bowing is more common in loosely knitted fabrics and is caused by interactions that occur between the forces exerted by the takedown rollers and the spreader board (Smith & Hudson, 1983). The spreader board controls fabric width and loop dimensions, as the fabric is collected at the bottom of the machine.

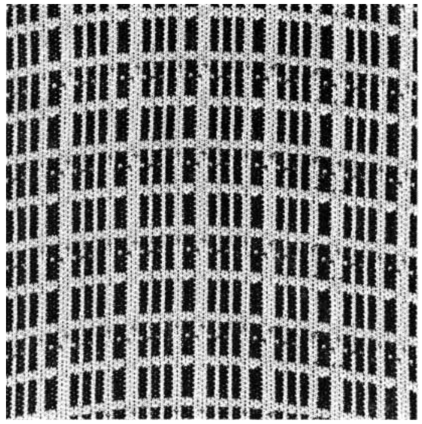


Figure 2.34: Forward bow (Stacey, 1971)

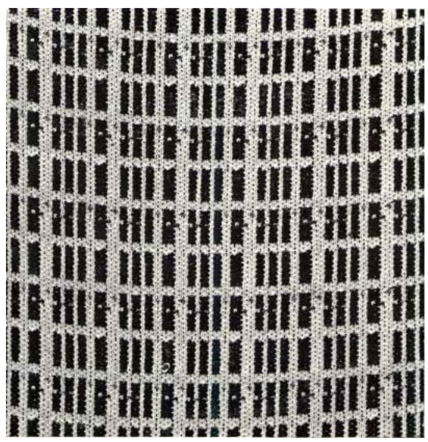


Figure 2.35: Backward bow (Stacey, 1971)

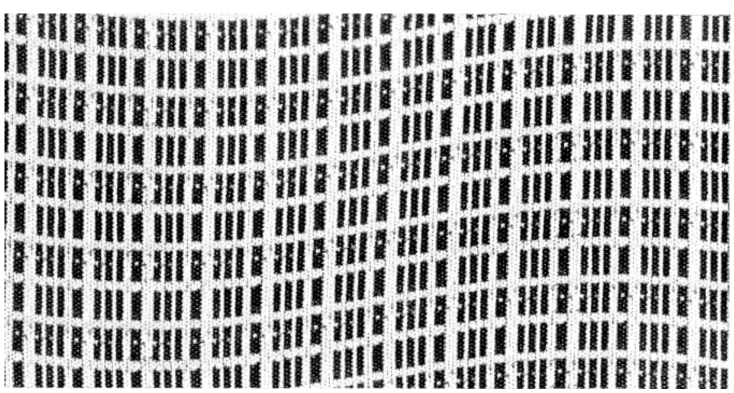


Figure 2.36: Compound bow (Stacey, 1971)

When structures are knitted side-by-side, the type of distortion likely to occur would be similar to banana distortion, shown in Figure 2.37. This is because the structure interactions would be along the adjoining line affecting both wales and courses.

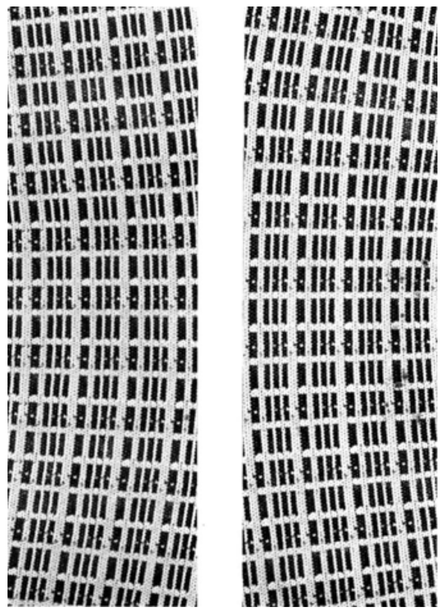


Figure 2.37: Banana distortion (Stacey, 1971)

When courses or wales are not at right angles to the fabric edges, they are referred to as being skewed. The term *skew* refers to distortion in both course and wale direction, but more specifically *skew* refers to courses and *spirality* refers to wales. In Figures 2.38 and 2.39, the diagrams on the left illustrate that skew can occur in S or Z direction. The fabric images on the right illustrate skew in the Z direction.

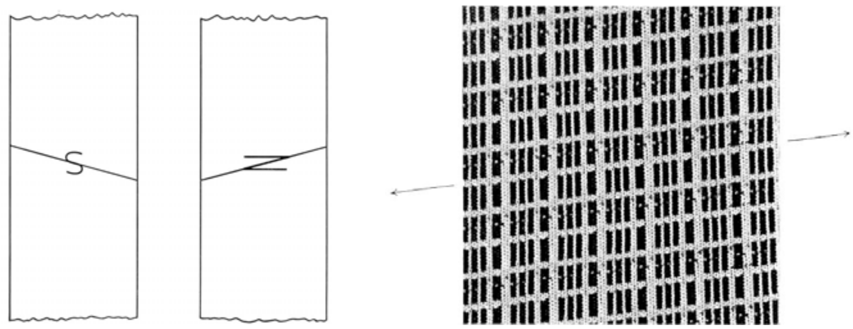


Figure 2.38: Skewed courses (Stacey, 1971)

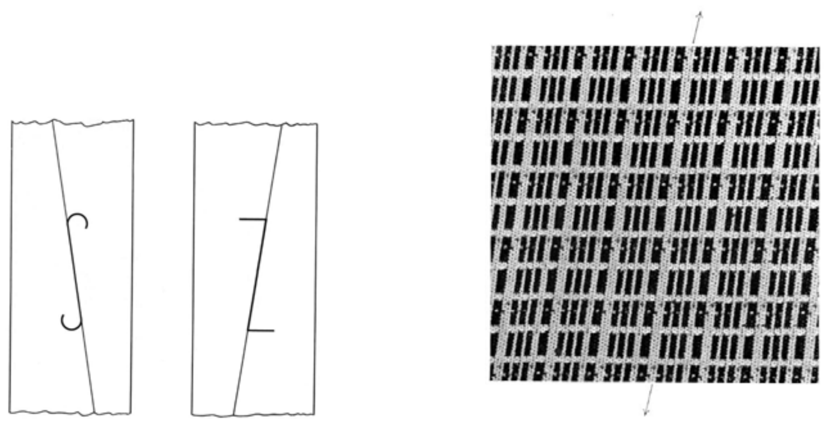


Figure 2.39: Skewed wales (Stacey, 1971)

2.15 Arc Measurements

The ASTM D-3882 Standard Test Method for Bow and Skew in Woven and Knitted Fabrics is used to determine bow and skew of courses in knitted fabrics. Test Method 3882 defines bow as a fabric condition that occurs when courses are displaced from a line perpendicular to the selvages and form one or more arcs across the width of the fabric (ASTM D-3882, 1999). This procedure requires the fabric to be laid on a smooth, horizontal service without tension as measurements are taken. Two measurements are required to calculate the percentage of bow (Figure 2.40).

Figure 2.40: Bow measurements (ASTM D-3882, 1999)

The baseline distance (BL) is the measurement along the bowline between the two edges. The bow distance (D) is the measurement perpendicular from the baseline distance to the maximum bow point. Percent bow is calculated using the formula:

$$\% \text{ Bow} = \frac{D}{BL} * 100$$

A different method in measuring distortion can be achieved by a map wheel. Arc measurements can be acquired using this device, shown in Figure 2.41. Prior to measuring, the scale is set. Then, measurement is obtained by rolling the unit along the desired route. The distance is displayed on the screen.

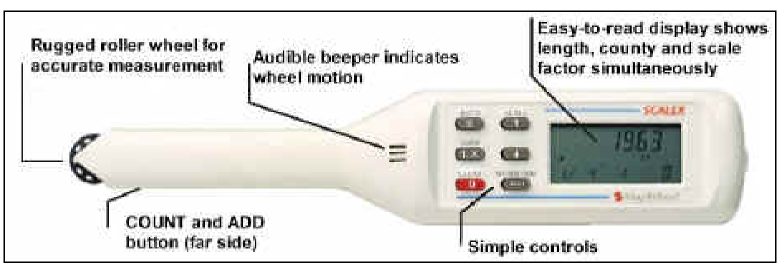


Figure 2.41: Electronic map wheel (Scalex, 2005)

Two lengths are required: L_L= long length, L_S= short length for the formula:

$$\text{Ratio} = \frac{L_L \text{ length}}{L_S \text{ length}}$$

In Figure 2.42, the first measurement, L_L, would come from the line where the two structures join; this length would be measured along the center of the wale. The second measurement, L_S, would be obtained from the lesser arcing wale.

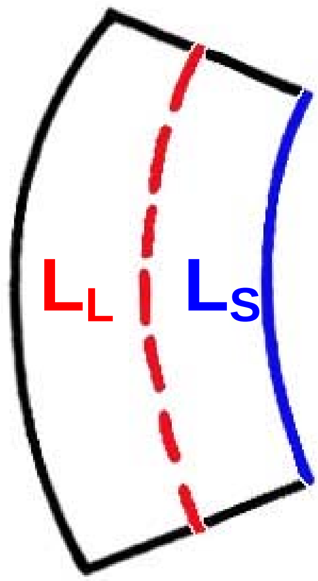


Figure 2.42: Map wheel measurements

CHAPTER THREE: METHODOLOGY

The purpose of this study is to determine whether arcing occurs when two different structures are knitted side-by-side. Samples were created using four different yarns and three knit structures knitted side-by-side at three different loop lengths. Amount of arcing in the samples was measured according to a method adapted from ASTM D-3882 Standard Test Method for Bow and Skew in Woven and Knitted Fabrics.

3.1 Knitting Machine

Fabrics were knitted using a Shima Seiki SES124-S v-bed flat knitting machine. The v-bed's design flexibility and machine capabilities were the reasons it was chosen for this research. The machine specifications are listed in Table 3.1. The knitting speed was set at 0.73 m/s and the knitting width was fixed on 320 needles or 45.6 inches wide. After knitting, all fabrics were sorted by yarn type and stored at room temperature in separate bins to prevent contamination from dirt and foreign fibers. All knitting was completed before the cutting and measuring process was initiated to ensure consistent testing conditions.

Table 3.1: Machine Specifications

Machine Manufacturer	Shima Seiki
Machine Type	Computerized Flat Knitting Machine
Machine Model	SES124-S
Machine Gauge	7
Type of Needles	Latch needle with transfer clip
Knitting Speed	0.73 meters/second
Minimum Yarns Fed	2 (acrylic, polyester, polypropylene)
Maximum Yarns Fed	4 (wool)
Full Bed Width	47 inches (119.38 cm)
Knitting Width	45.6 inches (115.8 cm) or 320 needles

3.2 Negative Feed

Negative feed was used to control loop length and to get the loop change as equal as possible between tight and medium loop lengths and between medium and loose loop lengths. In observing fabric distortion, using such a loop length approach, it was expected that it would be possible to predict how the fabric would lie in one-structure fabrics, and also predict how one structure would influence another structure in two-structure fabrics.

3.3 Loop Length

Knitters have the option to choose the tightness of knitting. Tight, medium, and loose loop lengths were selected for this experiment to show distinct differences in fabric tightness. The stitch cam setting on the machine for a tight loop length was 30, a medium loop length was 40, and a loose loop length was 50.

The one-structure fabrics produced for this study were single jersey, 1x1 rib, and moss stitch. The two-structure fabrics produced consisted of single jersey/1x1 rib, single jersey/moss, and 1x1 rib/moss. The visual stitch density was determined to verify the impact of loop change on one-structure and two-structure fabrics. The visual stitch density was used instead of stitch density because the term *stitch density* is the product of wale density and course density (Textile, 2002), which refers only to fabrics that consist of all identical loops, such as single jersey fabric (Smith, 2004). Therefore, the visual counts of loops were conducted due to the combination of different loop configurations in the 1x1 rib and moss stitch fabrics. In one-structure fabrics, visual stitch density decreased as loop length increased (Figure 3.1) confirming the effect of changing the loop length setting.

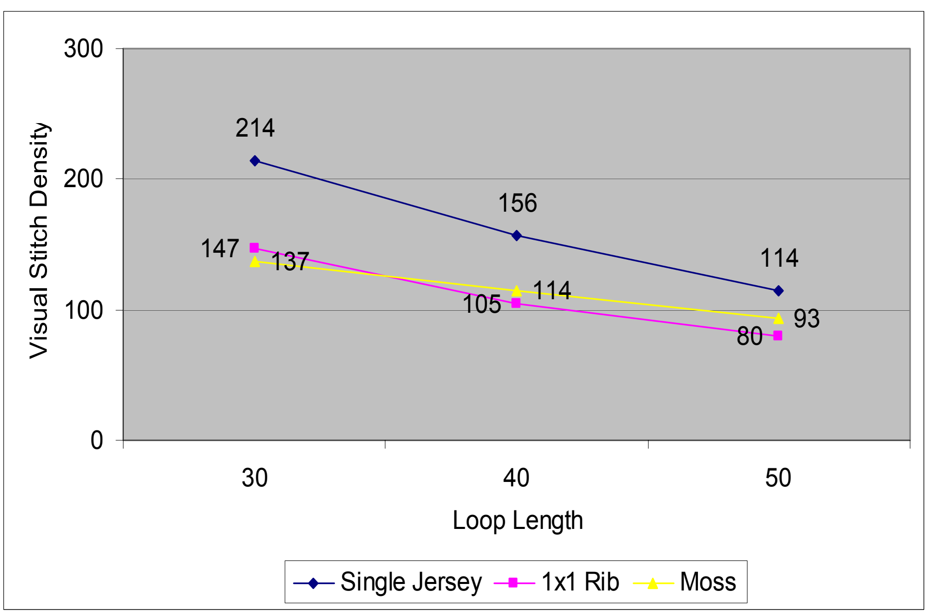


Figure 3.1: Average visual stitch density for one-structure fabric

The visual stitch density for one-structure fabrics was calculated by multiplying courses per inch (cpi) by wales per inch (wpi) in the formula:

$$\text{visual stitch density for one-structure fabrics} = \text{cpi x wpi}$$

Although, in two-structure fabrics, visual stitch density ratios were not useful in verifying loop change (Figure 3.2), this can be explained by the variation in tightness between structures. When combined, two structures compensated for each other's tightness.

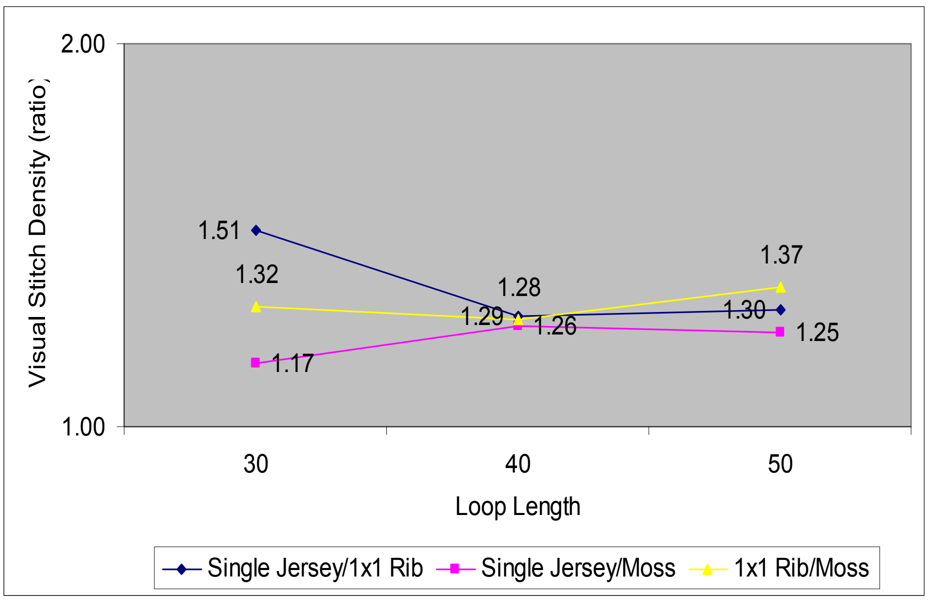


Figure 3.2: Average visual stitch density for two-structure fabric

The visual stitch density ratio was calculated by dividing the greater cpi and wpi values by the lesser cpi and wpi values in the formula:

$$\text{visual stitch density for two-structure fabrics (ratio)} = \frac{> \text{cpi x wpi}}{< \text{cpi x wpi}}$$

Visual stitch density data is listed in Appendix E.

3.4 Yarn

Four specific yarns were chosen for this experiment. The yarns were selected due to their individual characteristics (Table 3.2) as well as their availability. The yarns varied in terms of fiber content, fiber type (staple and filament), and yarn size. The number of yarn ends used in constructing the samples also varied from fiber type to fiber type. It was anticipated that each of these could potentially influence arcing of a knit sample when two structures were knitted side-by-side.

The spun yarns, acrylic and wool, provide volume and bulk in a knit fabric. The fullness of the yarn results from protruding fibers that may influence the effect of knitting two structures side-by-side in a fabric. The two filament yarns, polyester and polypropylene also exhibit volume and bulk, but not to the extent of the spun yarns, because they have lower total deniers. Polyester and polypropylene yarns used for this experiment were textured and bulked and held together by air entanglement.

The denier of each yarn was matched as closely as possible. In creating samples, each group of yarns was fed into one yarn carrier in the knitting machine. The machine utilizes 7 needles per inch (npi), which limits yarn size that may be used. In this experiment, the denier range of 1200 to 1328 was used to produce fabric in three variations of tight, medium, and loosely knit fabrics. In Table 3.2, a low specific gravity fiber density yarn is a very bulky yarn, which indicates a full yarn. Additional yarn information is listed in Appendix D.

Table 3.2: Yarn Specifications

Fiber Type	Yarn Type	Denier	# Of Filaments	Denier per Filament	Fiber Density
Acrylic	Spun	1328	none	none	Low
Wool	Spun	1328	none	none	Low
Polypropylene	Filament	1300*	288	4	Low
Polyester	Filament	1200*	136	2	High

*Total denier of two yarns

Denier per filament was calculated for the filament yarns by the using the formula:

$$\frac{\text{denier}}{\text{number of filaments}} = \text{denier per filament}$$

$$\frac{\text{650 denier}}{\text{288 filaments}} = \text{2 dpf Polypropylene}$$

$$\frac{\text{600 denier}}{\text{136 filaments}} = \text{4 dpf Polyester}$$

3.5 Knit Structures

Three weft knit structures were chosen for this experiment: single jersey, 1x1 rib, and the moss stitch. Single jersey is a common structure that is used extensively because it has a high production rate and is relatively inexpensive to produce, but it is easily distorted due to its simplicity and inherent spirality and skew. Skew is introduced during the knitting process when courses do not knit horizontally, but rather on an incline.

The 1x1 rib is a common structure, normally used for trim or in the body portion of garments. It is a rather unstable fabric and has tremendous widthwise extensibility. The 1x1 rib is the simplest and most unstable rib fabric, more easily distorted than single jersey especially in the width.

A more stabilized purl, i.e. the moss stitch, was chosen for this experiment due to its balance and rigidity compared to the plain purl structure. Plain purl is extensible lengthwise, but the moss stitch structure is one of the most stable purl fabrics both lengthwise and widthwise. The moss stitch was selected to be the controlling, stable structure in this experiment.

Each of the three structures was knitted into fabric and the images of these one-structure fabrics are located in Appendix A. In addition, each structure was knitted beside another structure to create a two-structure fabric. Images of two-structure fabrics are shown in Appendix B.

3.6 Dry Relaxed State

The fabrics were conditioned and measured in the dry relaxed state in the Digital Design Lab at North Carolina State University. Conditions in the lab were at average room temperature 68-77^{o}F (20-25^{o}C), 20-25% relative humidity. Prior to measuring weight, fabric swatches were conditioned in the T-PACC, Textile Protection and Comfort Center at the College of Textiles for 24 hours at 21^{o}C, 65% relative humidity.

3.7 Fabric Cutting

A template for cutting samples was created using Accumark Professional Edition software provided by Gerber Technology. The size of the template was 8.5

inches x 4.5 inches (21.6 cm x 11.4 cm). Each fabric was laid flat and cut on a computer driven cutter to ensure accurate and consistent sample dimensions. The cutter used was the GGT Cutting Edge- DCS 1500 Sample Cutter.

For each yarn type, 20 samples were cut from each fabric tightness for each structure combination with the exception of the polypropylene fabric from which a minimum of 12 samples were cut depending on the availability of the fabric. The number of samples cut for the polypropylene fabric was limited by the availability of the polypropylene yarns. Twenty samples were selected to ensure an adequate number of samples for purposes of statistical analysis. Samples were cut so that the combination line (the line where the two structures join) was centered in the sample. Another template was created for cutting samples to measure weight in grams. The size of the template was 5 inches x 5 inches (12.7 cm x 12.7 cm). Weight samples were hand cut to facilitate cutting efficiency. In summary, Figure 3.3 shows sample cutting for fabric from each of the four yarn types. Weight raw data is listed in Appendix F.

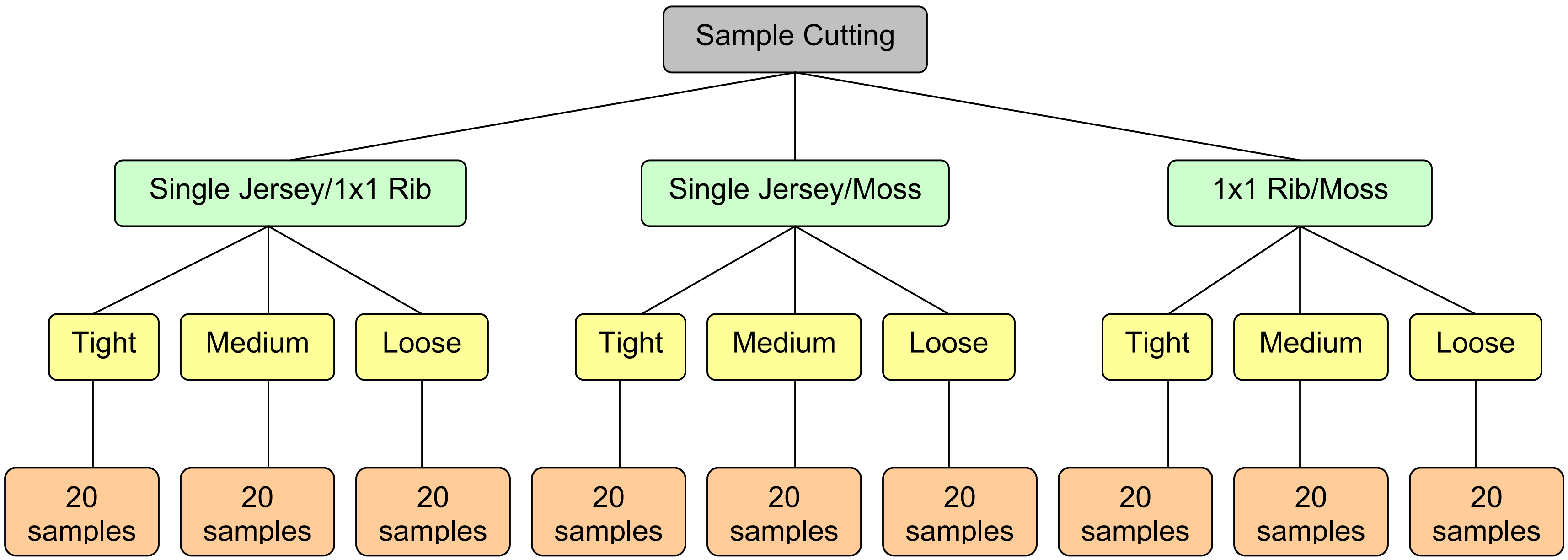


Figure 3.3: Sample Cutting for each yarn type

3.8 Arc Measurements and Calculations

The ASTM D-3882 Standard Test Method for Bow and Skew in Woven and Knitted Fabrics was used as a guide to develop a method in measuring arc in the knit fabric samples. This ASTM standard focuses on measuring bow, the bending of courses; however, the focus of this research is on the bending of wales and is referred to as *arcing*. The test method was also modified to accommodate a smaller sample size rather than using rolls or bolts of fabric.

There are two measurements required for this test method, arc distance and baseline distance. The baseline distance was measured along the line where two structures meet, from one edge of the fabric to the other. The arc distance is measured perpendicular to the baseline distance at the maximum arc point. The fabric samples were consistently positioned with the arc towards the left (Figure 3.4). Therefore, the single jersey was always positioned to the right of the 1x1 rib and always positioned to the left of the moss stitch. The 1x1 rib was always positioned on the left side, and the moss stitch was always positioned on the right. In the figures, wales appear vertically and courses appear horizontally.

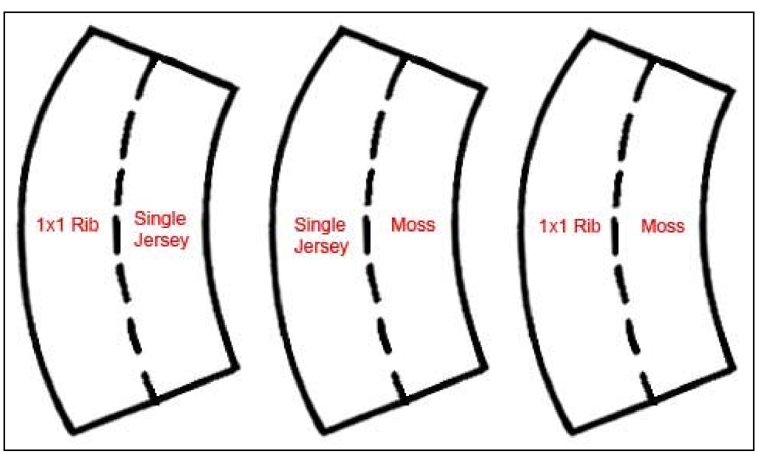


Figure 3.4: Measurement position

Arc distance and baseline distance were measured one time for each sample as shown in Figure 3.5. The distance between the two edges was measured to the nearest 1/16 inch (1mm) with a twelve inch ruler and was recorded as the baseline distance. The greatest distance perpendicular from the baseline to the combination line was measured to the nearest 1/16 of an inch (1mm) with a twelve inch ruler and was recorded as the arc distance. Arcing measurements are listed in Appendix G.

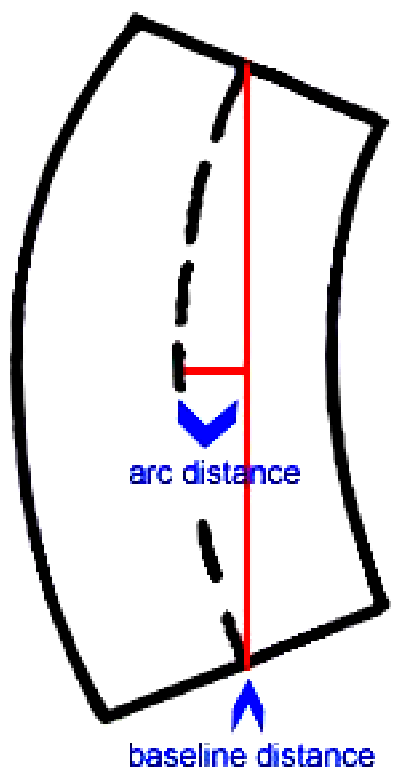


Figure 3.5: Sample measurements

- **Black outline represents the dry relaxed state of the sample.**
- **Black dotted line represents the line where two structures join.**
- **Red lines represent the straight measured lengths.**

The arc distance was divided by baseline distance for each measurement and these values were averaged. Once the averages were determined, the overall percent curvature was calculated using the formula (ASTM D-3882) for each fabric combination:

$$\% \text{ curvature} = \frac{\text{average arc distance}}{\text{average baseline distance}} \times 100$$

3.9 Documentation

The arcing fabric samples were documented by digital photography. The fabric shape varied according to the amount of arc, but the overall shape is shown in Figure 3.6. A copy stand was used to take still shots and to ensure the camera lens was always at an equal distance to the fabric surface. The camera lens was 12 inches (30.48 cm) from the surface of the fabric. Lighting was adjusted according to the color of the fabric in order to get clear shots of the knit structure. The pictures were downloaded into the computer and cropped to a standard size using Adobe Photoshop 7.0. Two-structure arcing fabric images are listed in Appendix C.

Figure 3.6: Fabric sample

3.10 Statistical Analysis

A series of t-tests were conducted to determine whether significant differences in arcing existed among two-structure knit fabrics that varied in loop length, structure type, and yarn type. This inference test compares mean arcing values for samples from two populations (Inferences, 2004). Both null and alternative hypotheses were developed as a foundation for the statistical analysis. An alpha level of .05 was used for all statistical tests.

The following null and alternative hypotheses were developed for comparing knit fabrics of different loop lengths:

$H1a_0$: There is no significant difference in arcing between the tight and medium knit fabrics.

$H1a_1$: There is a significant difference in arcing between the tight and medium knit fabrics.

$H1b_0$: There is no significant difference in arcing between the tight and loosely knit fabrics.

$H1b_1$: There is a significant difference in arcing between the tight and loosely knit fabrics.

$H1c_0$: There is no significant difference in arcing between the medium and loosely knit fabrics.

$H1c_1$: There is a significant difference in arcing between the medium and loosely knit fabrics.

The following null and alternative hypotheses were developed for comparing alternative structure combinations in two-structure knit fabrics:

$H2a_0$: There is no significant difference in arcing between the Single Jersey/1x1 Rib and the Single Jersey/Moss fabrics.

$H2a_1$: There is a significant difference in arcing between the Single Jersey/1x1 Rib and the Single Jersey/Moss fabrics.

$H2b_0$: There is no significant difference in arcing between the Single Jersey/1x1 Rib and the 1x1 Rib/Moss fabrics.

$H2b_1$: There is a significant difference in arcing between the Single Jersey/1x1 Rib and the 1x1 Rib/Moss fabrics.

$H2c_0$: This is no significant difference in arcing between the Single Jersey/Moss and the 1x1 Rib/Moss fabrics.

$H2c_1$: There is a significant difference in arcing between the Single Jersey/Moss and the 1x1 Rib/Moss fabrics.

The following null and alternative hypotheses were developed for comparing two-structure fabrics made from spun yarns and from filament yarns:

$H3_0$: There is no significant difference in arcing between two-structure fabrics made from spun yarns and two-structure fabrics made from filament yarns.

$H3_1$: There is a significant difference in arcing between two-structure fabrics made from spun yarns and two-structure fabrics made from filament yarns.

The following null and alternative hypotheses were developed for comparing two-structure fabrics made from acrylic and from wool yarns:

$H4_0$: There is no significant difference in arcing between two-structure fabrics made from acrylic yarns and two-structure fabrics made from wool yarns.

$H4_1$: There is a significant difference in arcing between two-structure fabrics made from acrylic yarns and two-structure fabrics made from wool yarns.

The following null and alternative hypotheses were developed for comparing two-structure fabrics made from polyester and from polypropylene yarns:

$H5_0$: There is no significant difference in arcing between two-structure fabrics made from polyester yarns and two-structure fabrics made from polypropylene yarns.

$H5_1$: There is a significant difference in arcing between two-structure fabrics made from polyester yarns and two-structure fabrics made from polypropylene yarns.

CHAPTER FOUR: RESULTS AND DISCUSSION

This section will discuss the hypotheses test results in comparing two-structure knit fabrics of different loop lengths, structure combination, and fabrics made from spun and filament yarns on their influences on arc.

4.1 The Effect of Loop Length on Arc

$H1a_0$: There is no significant difference in arcing between the tight and medium knit fabrics.

$H1a_1$: There is a significant difference in arcing between the tight and medium knit fabrics.

Tightly knit fabric had higher arcing values (M = .034093, SD = .027676) than medium knit fabric (M = .028627, SD = .022847), $t(433) = 2.30102$, $p = .021865$. This is significant because $p \leq .05$. Based on the results, the null hypothesis was rejected. It was concluded that there was a significant difference in arcing between the tight fabric and medium fabric, and that the alternative hypothesis is true.

The tightly knit fabric arced more than the medium knit fabric (Figure 4.1) because the tight fabric was more rigid. The loops in the tight fabric did not have space to move around in order to compensate for the distortion from the neighboring structure. Therefore, the only outlet for distortion was the bending of wales, which caused the fabric to arc. The medium knit fabric had a lower percentage of arcing because the loops had more room to move around in a less rigid fabric. Therefore, the neighboring structure was able to compensate for the distortion from the other structure, which caused less arcing.

Figure 4.1 shows the arcing percentages for each fabric tightness. The fabric tightness: tight, medium, and loose were indicated by their corresponding tightness settings 30, 40, and 50, respectively. All t-test results are listed in Appendix H.

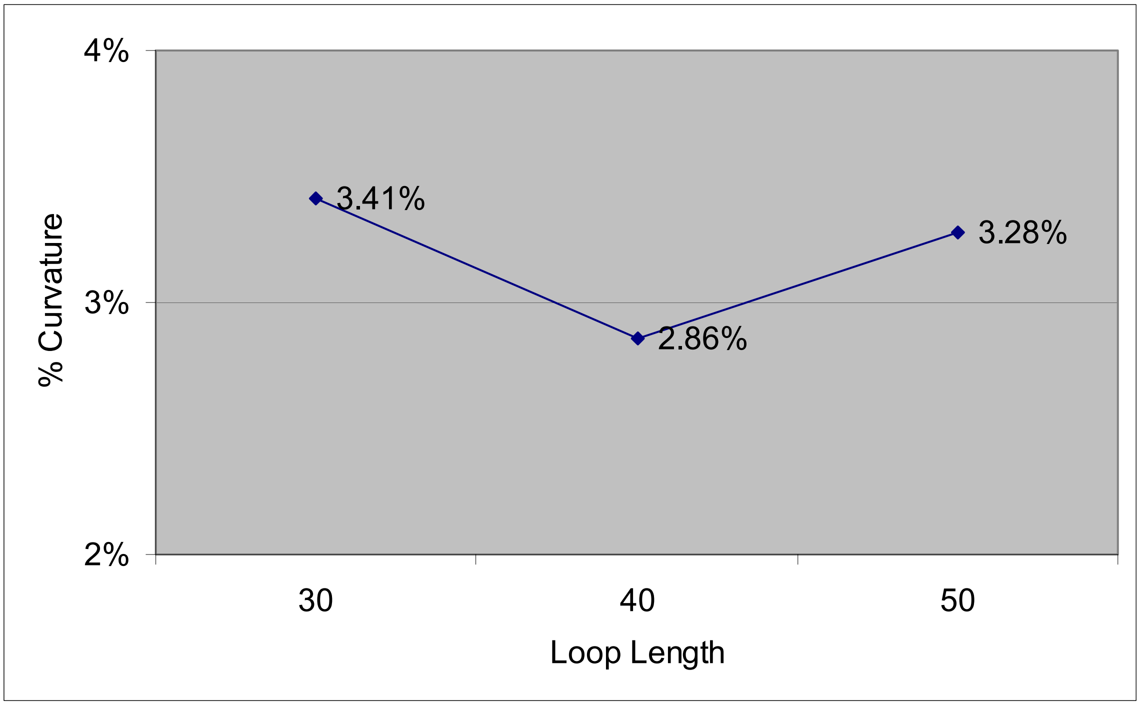


Figure 4.1: Loop Length vs. Percent Curvature

H1b$_0$: There is no significant difference in arcing between the tight and loosely knit fabrics.

H1b$_1$: There is a significant difference in arcing between the tight and loosely knit fabrics.

Tightly knit fabric (M = .034093, SD = .027676) and loosely knit fabric

(M = .032794, SD = .025337), t(451) = .526203, p = .599006 had similar arcing values. Test results failed to support rejecting the null hypothesis, and it was concluded that there was no significant difference in arcing between tight fabric and loosely knit fabric.

Although hypothesis test results of $1b_0$ indicated that there was no significant difference between tight and loosely knit fabric (Figure 4.1), it was determined that all tightnesses exhibited arcing and tightly knit fabric exhibited significantly more than medium knit fabrics. As can be seen in the plots in Figure 4.1, all tightnesses exhibited arcing of about 30%. In tightly knit fabric, short loops have limited space to move in order to compensate the distortion from neighboring structures. Therefore, the only outlet for distortion was through the bending of wales that caused the fabric to arc. The loosely knit fabric exhibited similar arcing percentages because distortion is more susceptible in loosely constructed fabric due to easily distorted loops. The neighboring structures were able to compensate for distortions from the other structure.

$H1c_0$: There is no significant difference in arcing between the medium and loosely knit fabrics.

$H1c_1$: There is a significant difference in arcing between the medium and loosely knit fabrics.

Medium knit fabric (M = .028627, SD = .022847) and loosely knit fabric (M = .032794, SD = .025337), t(470) = -.1882735, p = .060354 had similar arcing values. Test results failed to support rejecting the null hypothesis, and it was concluded that there was no significant difference in arcing between medium fabric and loosely knit fabric.

The medium and loosely knit fabrics (Figure 4.1) exhibited similar arcing due to the amount of open space for loop to move. Although, loose constructions were susceptible to greater arcing, they also have space to compensate for distortions from the other structure. The greater length of the loop created open space for loops to move around; therefore neighboring structures were able to compensate for distortions from the other structure. The medium fabric provided less space for loop movement, but there was enough space to allow the neighboring structure to compensate for distortion from the other structure. Therefore, medium and loosely constructed knit fabrics had similar influences on arcing in two-structure fabrics.

4.2 The Effect of Two-Structure Fabrics on Arc

$H2a_0$: There is no significant difference in arcing between the Single Jersey/1x1 Rib and the Single Jersey/Moss fabrics.

$H2a_1$: There is a significant difference in arcing between the Single Jersey/1x1 Rib and the Single Jersey/Moss fabrics.

Single Jersey/1x1 Rib fabric had higher arcing values (M = .030836, SD = .023685) than Single Jersey/Moss fabric (M = .012344, SD = .012489), $t(349) = 10.5305$, $p = .000000$. This is significant because $p \leq .05$. Based on test results, the null hypothesis was rejected. It was concluded that there was a significant difference in arcing between the Single Jersey/1x1 Rib fabric and Single Jersey/Moss fabric, and that the alternative hypothesis is true.

The arcing difference between the Single Jersey/1x1 Rib and Single Jersey/Moss fabrics was due to the difference of structural stability in the 1x1 rib and moss structures (Figure 4.2). When an unstable structure was knitted beside a more stable structure, the more stable structure distorted the less stable one. In the Single Jersey/1x1 Rib, the arcing was created when the single jersey distorted the 1x1 rib, versus the 1x1 rib distorting the single jersey. This occurred because the 1x1 rib was more easily distorted than the single jersey structure. Alternatively, when the stable moss structure was knitted beside the single jersey, distortions were kept to a minimum because the single jersey resisted deformation to some degree. It was determined that when a greater difference of structural stability existed between structures that were knit side-by-side, more arcing occurred. Alternatively, when a lesser difference of structural stability existed between adjoined structures, less arcing occurred.

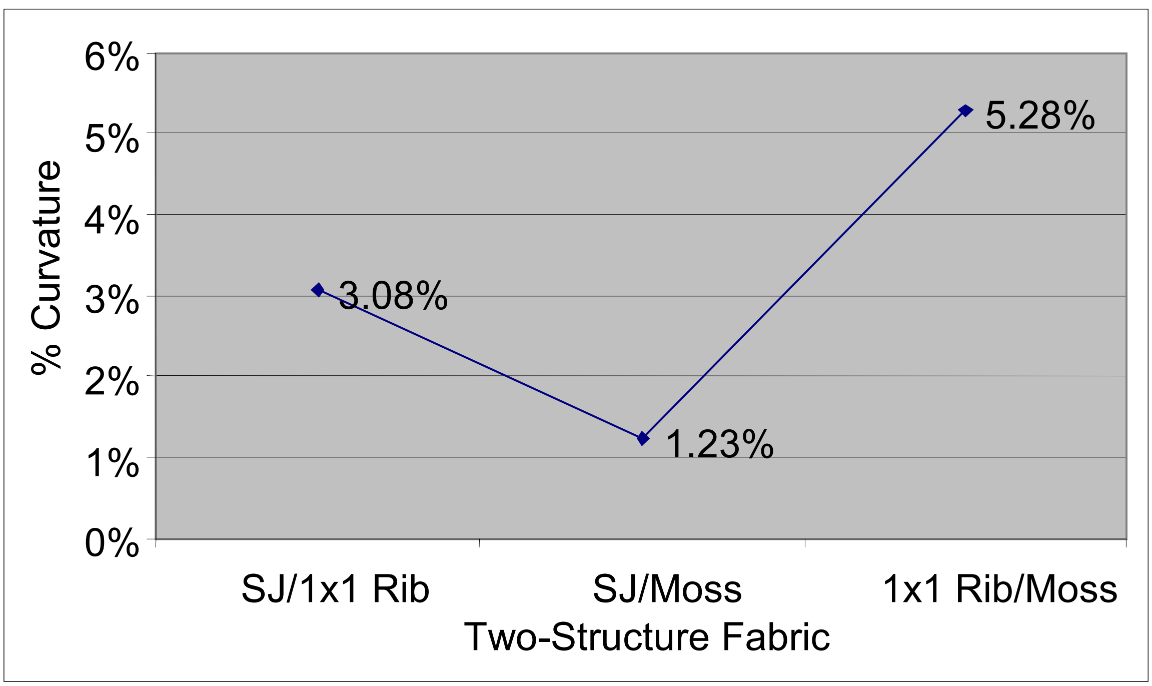


Figure 4.2: Two-Structure Fabric vs. Percent Curvature

H2b$_0$: There is no significant difference in arcing between the Single Jersey/1x1 Rib and the 1x1 Rib/Moss fabrics.

H2b$_1$: There is a significant difference in arcing between the Single Jersey/1x1 Rib and the 1x1 Rib/Moss fabrics.

Single Jersey/1x1 Rib fabric had lower arcing values (M = .030836, SD = .023685) than 1x1 Rib/Moss fabric (M = .052848, SD = .020000), t(449) = -10.7888, p = .000000. This is significant because $p \leq .05$. Based on test results, the null hypothesis was rejected. It was concluded that there was a significant difference in arcing between the Single Jersey/1x1 Rib fabric and 1x1 Rib/Moss fabric, and that the alternative hypothesis is true.

The arcing difference between the Single Jersey/1x1 Rib and 1x1 Rib/Moss fabrics were influenced by the difference of structural stability in the single jersey and moss structure (Figure 4.2). The moss structure resisted distortion more than the single jersey because the moss was inherently balanced and stable. Therefore, the 1x1 rib distorted to a greater amount when it was knitted beside the moss. Although, the single jersey was less stable than the moss, it resisted the distortion more than the 1x1 rib. As a result, the 1x1 rib distorted when it was knitted beside the single jersey, but the amount of distortion was lower in the Single Jersey/1x1 Rib fabric than the 1x1 Rib/Moss fabric.

H2c$_0$: This is no significant difference in arcing between the Single Jersey/Moss and the 1x1 Rib/Moss fabrics.

H2c$_1$: There is a significant difference in arcing between the Single Jersey/Moss and the 1x1 Rib/Moss fabrics.

Single Jersey/Moss fabric had lower arcing values (M = .012344, SD = .012489) than 1x1 Rib/Moss fabric (M = .052848, SD = .020000), $t(383) = -26.1309$, $p = .000000$. This is significant because $p \leq .05$. Based on test results, the null hypothesis was rejected. It was concluded that there was a significant difference in arcing between the Single Jersey/Moss fabric and 1x1 Rib/Moss fabric, and that the alternative hypothesis is true.

The arcing difference between the Single Jersey/Moss and the 1x1 Rib/Moss fabrics was due to the difference of structural stability in the single jersey and 1x1 rib structures (Figure 4.2). The instability of the 1x1 rib resulted from the ability to easily extend in width due to alternating front and back wales. Single jersey created less arcing because it consisted of all face loops, which limited extensibility and resisted distortion from the moss structure. In the 1x1 Rib/Moss fabric, the 1x1 rib was the unstable structure. When it was knitted beside the moss, a greater amount of arcing occurred than the Single Jersey/Moss fabric because the 1x1 rib structure was less stable than the single jersey structure.

4.3 The Effect of Spun and Filament Yarns on Arc

The yarns used to knit fabric samples were of different deniers (Figure 4.3), which contributed to the amount of arcing in fabric samples. These yarn images are consistent to one another with regard to scale.

a.

b.

c.

d.

Figure 4.3: Yarns used to knit fabric samples

a. Acrylic yarn of 664 denier

b. Wool yarn of 332 denier

c. Polyester yarn of 600 denier

d. Polypropylene yarn of 650 denier

$H3_0$: There is no significant difference in arcing between two-structure fabrics made from spun and two-structure fabrics made from filament yarns.

$H3_1$: There is a significant difference in arcing between two-structure fabrics made from spun and two-structure fabrics made from filament yarns.

Two-structure fabrics made from spun yarn had higher arcing values (M = .037087, SD = .025337) than two-structure fabrics made from filament yarn (M = .026204, SD = .024248), t(697) = 5.79968, p = .000000. This is significant because $p \leq .05$. Based on test results, the null hypothesis was rejected. It was concluded that there was a significant difference in arcing between the two-structure fabrics made from spun yarn and from filament yarn, and that the alternative hypothesis is true.

The two-structure knits made of spun yarns exhibited higher arcing percentages than those made of filament yarns (Figure 4.4). This could be due to the spirality influences as well as fiber density. Spun yarns were characterized by low fiber density, which influenced more arcing. The lighter weight, in addition to high volume and bulk, resulted in higher arcing percentages because loops had limited space to move around. This prevented a neighboring structure from compensating for distortion imposed by the other structure resulting in bending of wales, thus arcing. Two-structure knits made of filament yarns exhibited lower arcing percentages because they were less voluminous. The loops had more space to move around, which allowed a neighboring structure to compensate for distortions imposed by the other structure resulting in less arcing.

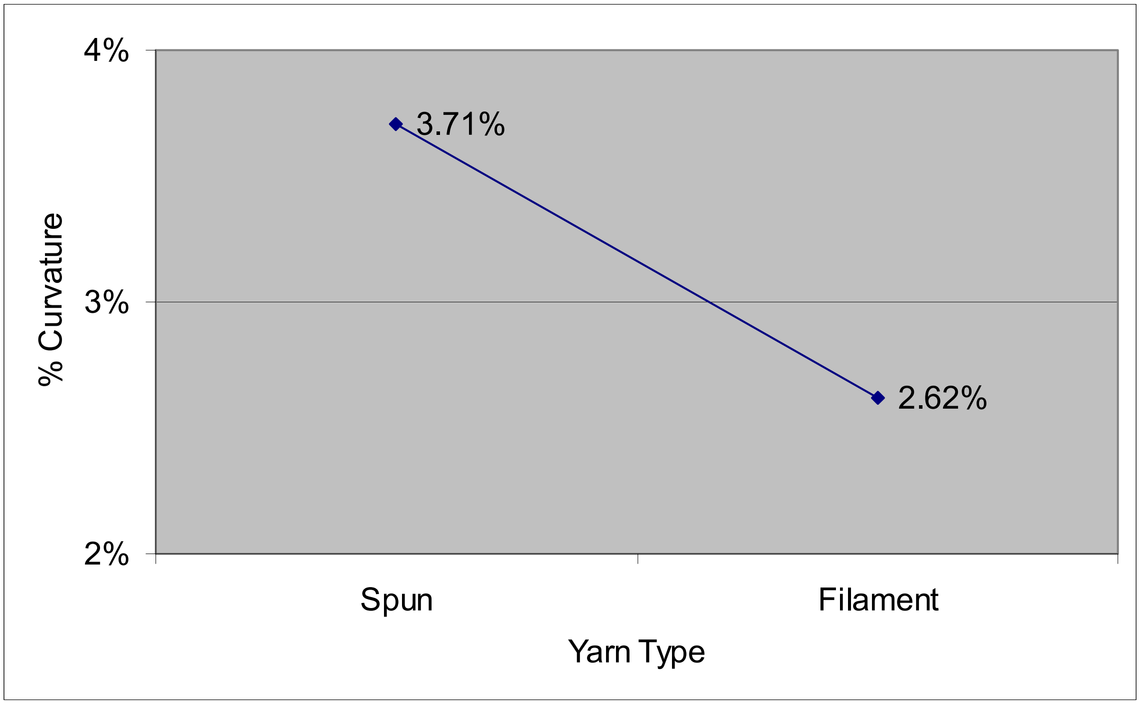


Figure 4.4: Yarn Type vs. Percent Curvature

4.4 The Effect Fiber Content in Spun Yarns: Acrylic and Wool

$H4_0$: There is no significant difference in arcing between two-structure fabrics made from acrylic and two-structure fabrics made from wool yarns.

$H4_1$: There is a significant difference in arcing between two-structure fabrics made from acrylic and two-structure fabrics made from wool yarns.

Two-structure fabrics made from acrylic yarn (M = .038243, SD = .027784) and two-structure fabrics made from wool yarn (M = .035931, SD = .022649), t(344)

= .864793, p = .387754 had similar arcing values. Test results failed to support rejecting the null hypothesis, and it was concluded that there was no significant difference in arcing between two-structure fabrics made from acrylic yarn and from wool yarn (Figure 4.5).

The spun yarns, acrylic and wool had the same denier = 1328 as well as similar fiber densities, 1.12 and 1.15 respectively. This similarity in denier and fiber density resulted in similar influences on arcing. Both yarns had bulk and volume, which made the fabric more rigid. Two-structure fabrics made from bulky yarn contained less open space for loops to move because the yarn volume occupied that space. Therefore, the rigid fabric prevented the neighboring structure from compensating for distortions from the other structure.

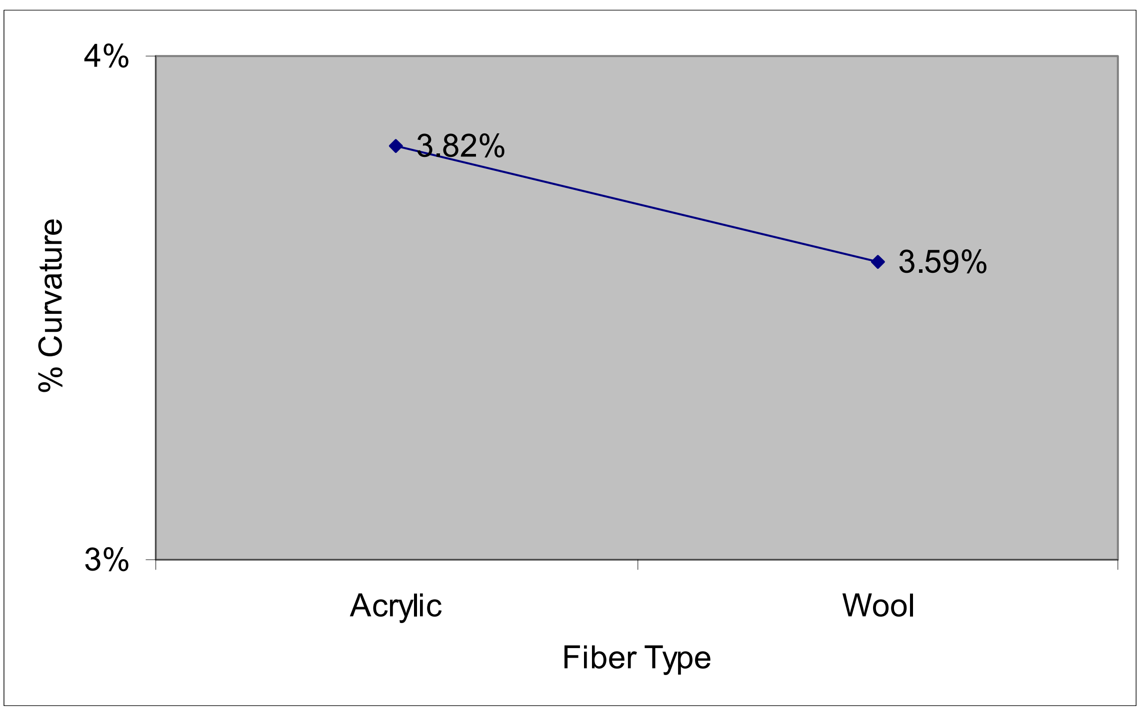


Figure 4.5: Spun Yarn vs. Percent Curvature

4.5 The Effect of Filament Yarns: Polyester and Polypropylene

$H5_0$: There is no significant difference in arcing between two-structure fabrics made from polyester and two-structure fabrics made from polypropylene yarns.

$H5_1$: There is a significant difference in arcing between two-structure fabrics made from polyester and two-structure fabrics made from polypropylene yarns.

Two-structure fabrics made from polyester yarn (M = .025510, SD = .020273) and two-structure fabrics made from polypropylene yarn (M = .026989, SD = .028142), $t(283) = -.548472$, $p = .583800$ had similar arcing values. Test results failed to support rejecting the null hypothesis, and it was concluded that there was no significant difference in arcing between two-structure fabrics made from polyester yarn and from polypropylene yarn (Figure 4.6).

The denier of polypropylene (1300 den) was greater than polyester (1200 den) while the fiber density of polypropylene was lower than polyester, 0.9 and 1.23 respectively. The relationship between fiber density and denier of these yarns balanced each other out in terms of the number of filaments. There were 136 filaments of polyester yarn and 288 filaments of polypropylene yarn. Since polypropylene was a lighter fiber than polyester, polypropylene had twice the number of filaments than polyester. Therefore, the relationship between fiber densities and denier resulted in similar influences on arcing in two-structure fabrics.

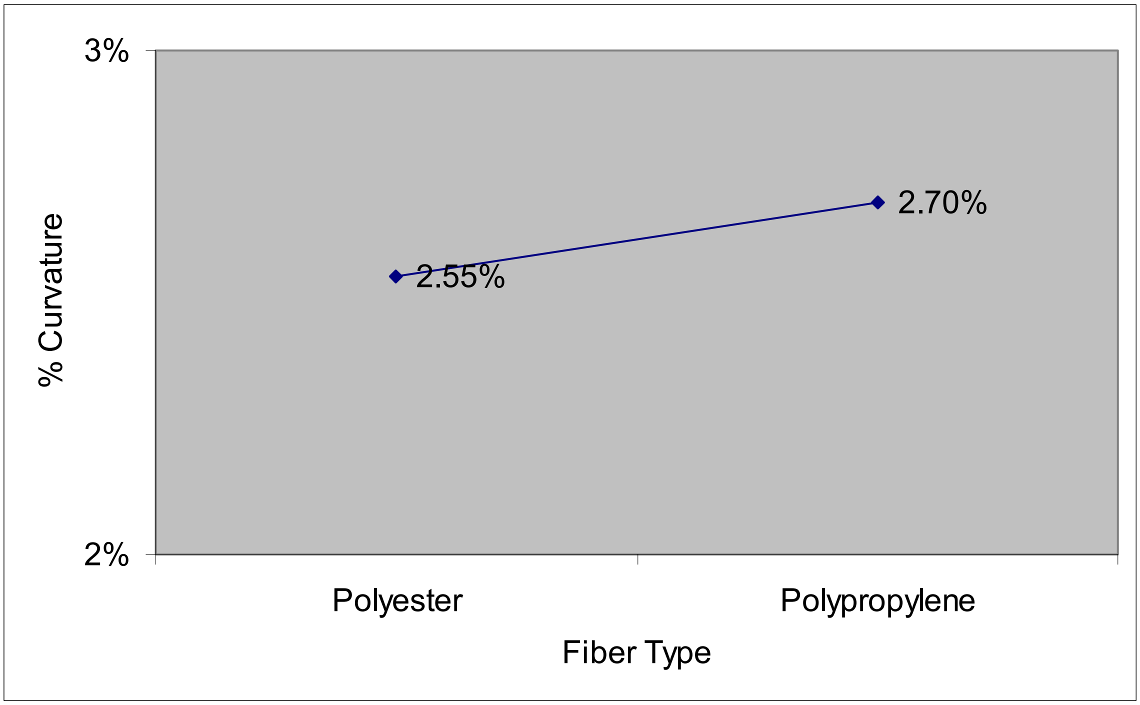


Figure 4.6: Filament Yarn vs. Percent Curvature

The results indicated that arcing occurred when two different structures were knitted side-by-side and arcing was effected by the combination of loop length and specific structures. It was determined that structural stability contributed highly to the amount of arcing. Fabric arcing was also influenced by yarn type and fiber density.

CHAPTER FIVE: CONCLUSION

5.1 Effects of Loop Length on Arc

It was determined that fabrics knit tightly and loosely were more susceptible to arcing. Less arcing occurred in the medium fabric compared to tightly and loosely knit fabrics. All fabric tightnesses exhibited arcing, tight more than medium and loose was similar to both tightly and medium knit fabrics.

5.2 Effects of Structure Interactions on Arc

Arcing occurred when two different structures were knitted side-by-side. Arcing was affected by the combination of specific structures and structural stability contributed highly to the amount of arcing. The most arcing occurred in the 1x1 Rib/Moss fabric because the 1x1 rib was the most easily distorted structure compared to single jersey and the moss stitch. An average amount of arcing occurred in the Single Jersey/1x1 Rib fabric because the difference of structural stability between structures was not significant. The least amount of arcing occurred in the Single Jersey/Moss fabric because the moss fabric maintained stability with little or no distortion to the single jersey.

5.3 Effects of Yarn Type on Arc

It was concluded that the spun yarns (acrylic and wool) produced more arcing than the filament yarns (polyester and polypropylene) in two-structure fabrics. In comparing the fiber types of acrylic and wool yarns, it was determined that these spun yarns had similar influences on arcing in two-structure fabrics. In comparison of polyester and polypropylene fibers, it was determined that these filament yarns had similar influences on arcing in two-structure fabrics. It was demonstrated that bulkier yarns made from staple fibers produced more arcing than less bulky yarns made from filaments. Therefore, the more yarn bulk that was present restricted loop movement. This limitation to loop movement caused loops to shift around the neighboring structure rather than compensating the loops from the neighboring structure, which produced greater arcing. This emphasizes the importance of yarn type versus fiber content in terms of arcing.

CHAPTER SIX: FUTURE RESEARCH

The research performed in this study provided methods and identified the occurrence of arcing when two different structures were knitted side-by-side. Given that this research was an overview of a new approach there were several recommendations for future research.

6.1 Different Size Sample

Different size samples could be used to determine the effects on arcing. During the cutting process, it was observed that sample size had influence the amount of arcing. The fabrics with short baseline distances created less arcing. A longer baseline distance produced more arcing, but there was a maximum point to where the amount of arcing evened out. Future studies could investigate the influence of sample size on arc.

6.2 Fabric Deformation

Arcing was the only deformation analyzed in this research. It was observed that buckling, where the plane of the fabric is affected, was more evident and pronounced in tightly knit fabrics versus loosely knit fabrics. In addition, the buckling observed in this study created an aesthetically pleasing effect, which represented rouching or ruffling techniques. Further studies on fabric buckling and possibly the relationship with knitted textile design could be undertaken.

6.3 Yarn Denier and Diameter

The yarns used in this experiment were not of equal deniers; further research could include yarns of equal deniers so fabrics can be readily compared to each other. The yarn diameter of each yarn varied accordingly to construction and fiber characteristics. Yarn testing can reveal the relationship between yarn characteristics and arcing. Further studies that incorporate yarn testing and their effects on the relaxed state of fabric are suggested.

6.4 Stability

Three basic structures: single jersey, 1x1 rib, and moss stitch were used in this experiment to demonstrate how the stability of each structure influenced the amount arcing. More complex knit structures of various stability levels are suggested for future research.

6.5 Testing Conditions

Fabrics were conditioned in an uncontrolled environment under the circumstances of the location of the knitting machine. Future conditioning of fabric samples under standard testing conditions 21^{o}C, 65% relative humidity is suggested to eliminate any discrepancies related to testing conditions and its effects on fabric relaxation.

6.6 Relaxed States

The fabrics were dry-relaxed in this experiment; therefore analyzing the fabrics in this state does not clearly reveal how the fabric will perform in use. Washing and drying the fabrics to become the wet or fully-relaxed state will better emulate consumer laundering instructions as well as performance standards. Also, fabric properties will change through washing and drying conditions depending on the fiber characteristics. A natural fiber such as wool tends to felt under agitation and hot water resulting in a very compact and dense fabric. Alternatively, synthetic acrylic fibers do not have the ability to felt together, which would result in a looser fabric. Analyzing fabrics in a wet-relaxed or fully-relaxed state is suggested for future research.

6.7 Textile Design

Arcing can be used to create volume and form in knitted fabrics to imitate ruffling or rouching effects without creating seams. For example, rouching is a technique of gathering fabric, which produces a rippling effect and may be used to create fullness in the bust area. Arcing may produce similar effects when a compact structure (stable) is knitted with an extensible structure (unstable). Therefore, further experimentation in knitted textile design that incorporates the arcing will contribute to the potential of this knitting technique.

6.8 Arc Control or Prediction

The fabric distortions (i.e. bowing and skewing) mentioned in this study are considered negative aspects in fabric production, however fabric distortions such as arcing and buckling created in knit fabrics may be considered desirable fabric characteristics. Experimentation with various yarn mediums (metals and other fiber types) which incorporate arcing in knit fabrics is suggested to determine the possibilities and limitations of creating form by means of fabric arcing.

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APPENDICES

APPENDIX A: ONE-STRUCTURE FABRIC

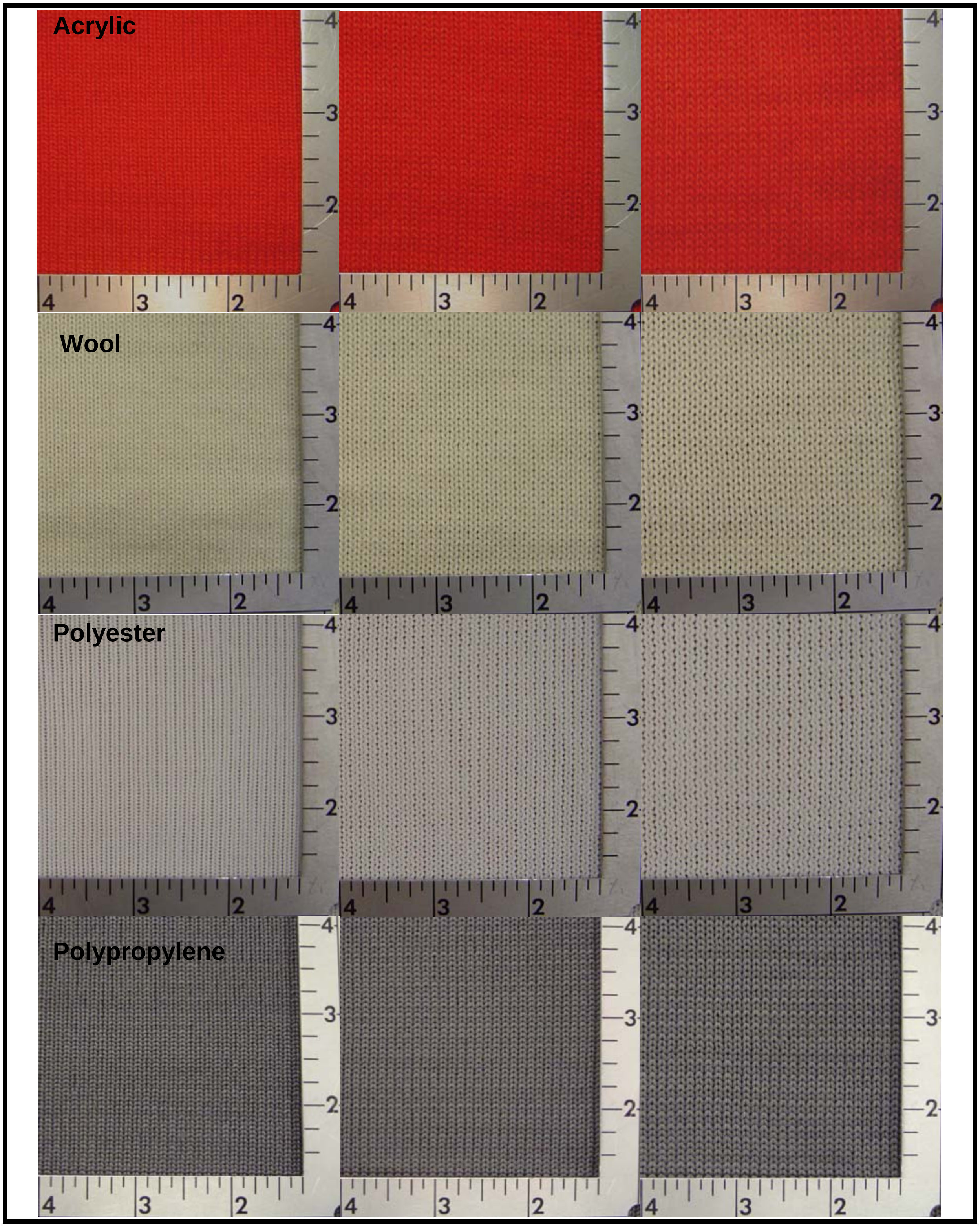

Figure A1: Single Jersey - Tight, Medium, Loose

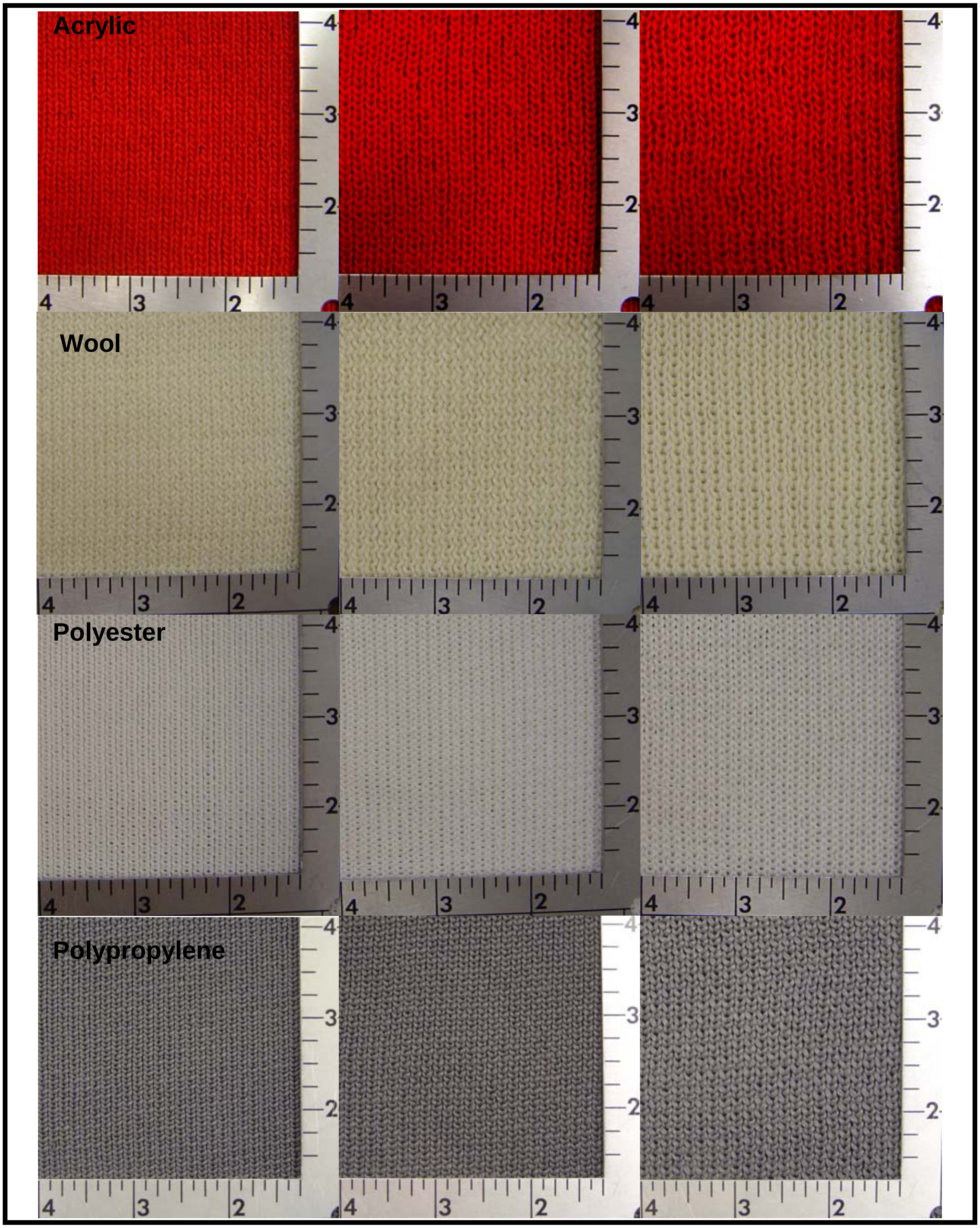

Figure A2: 1x1 Rib - Tight, Medium, Loose

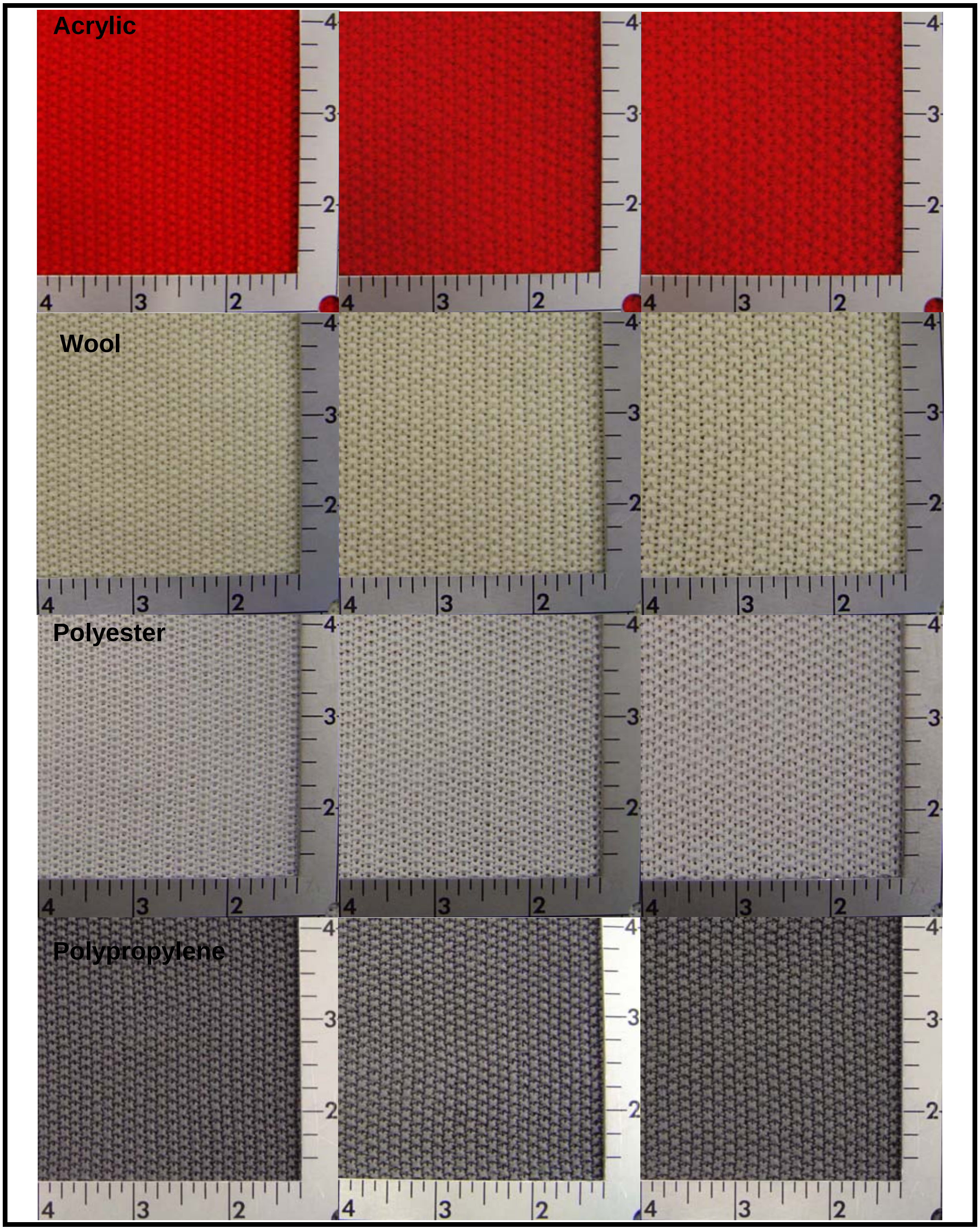

Figure A3: Moss Stitch - Tight, Medium, Loose

APPENDIX B: TWO-STRUCTURE FABRIC

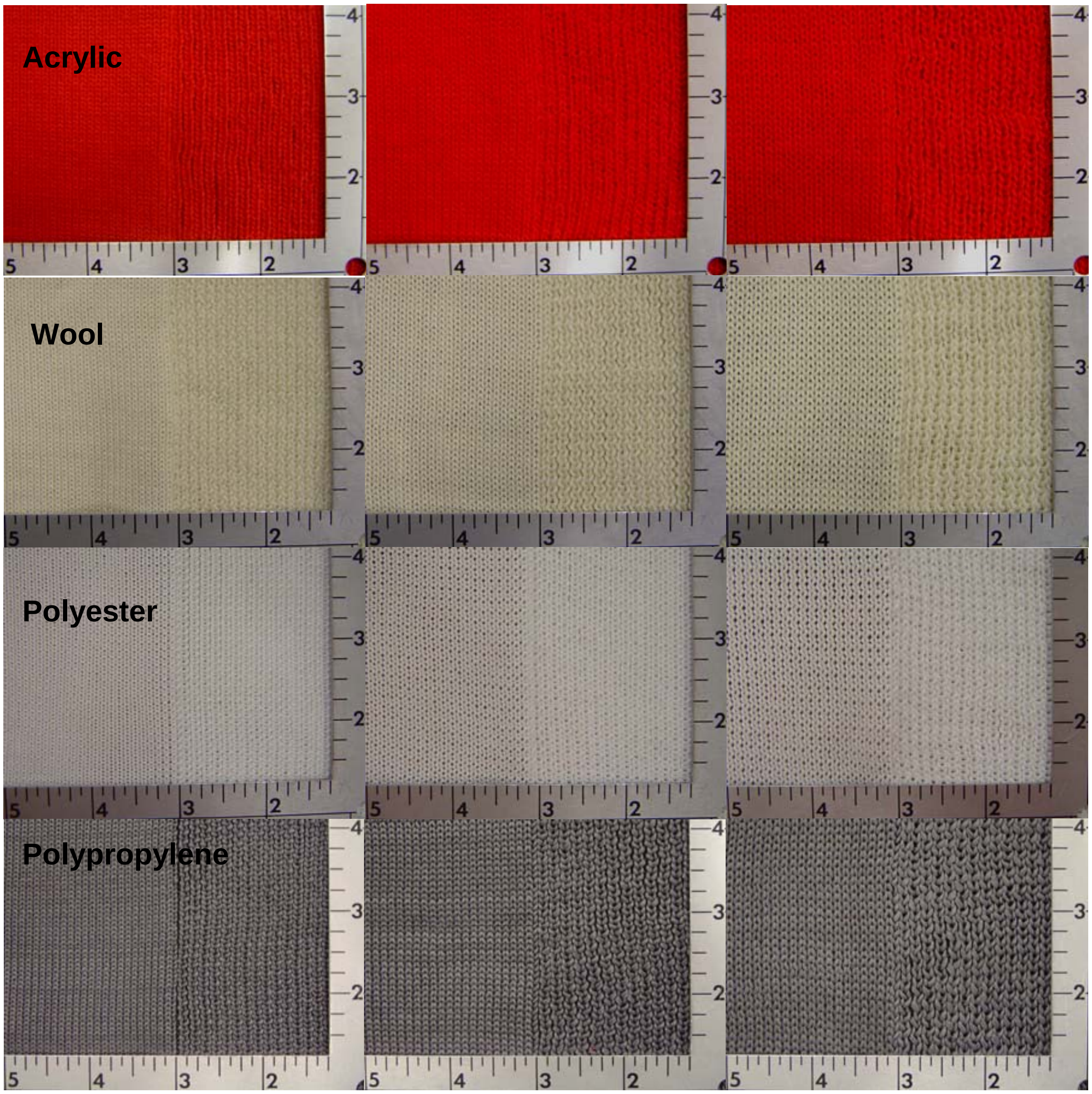

Figure A4: Single Jersey/1x1 Rib - Tight, Medium, Loose

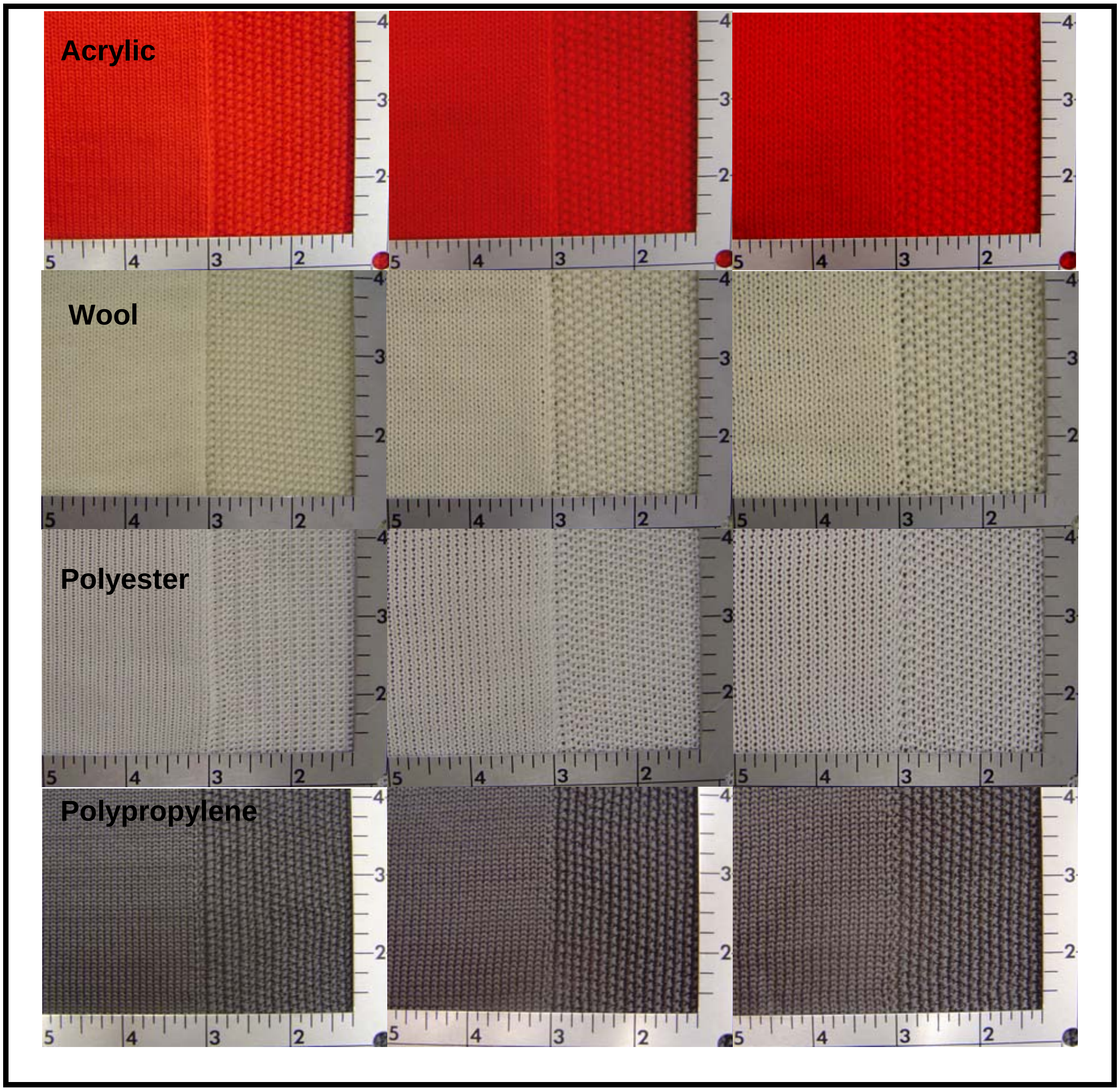

Figure A5: Single Jersey/Moss - Tight, Medium, Loose

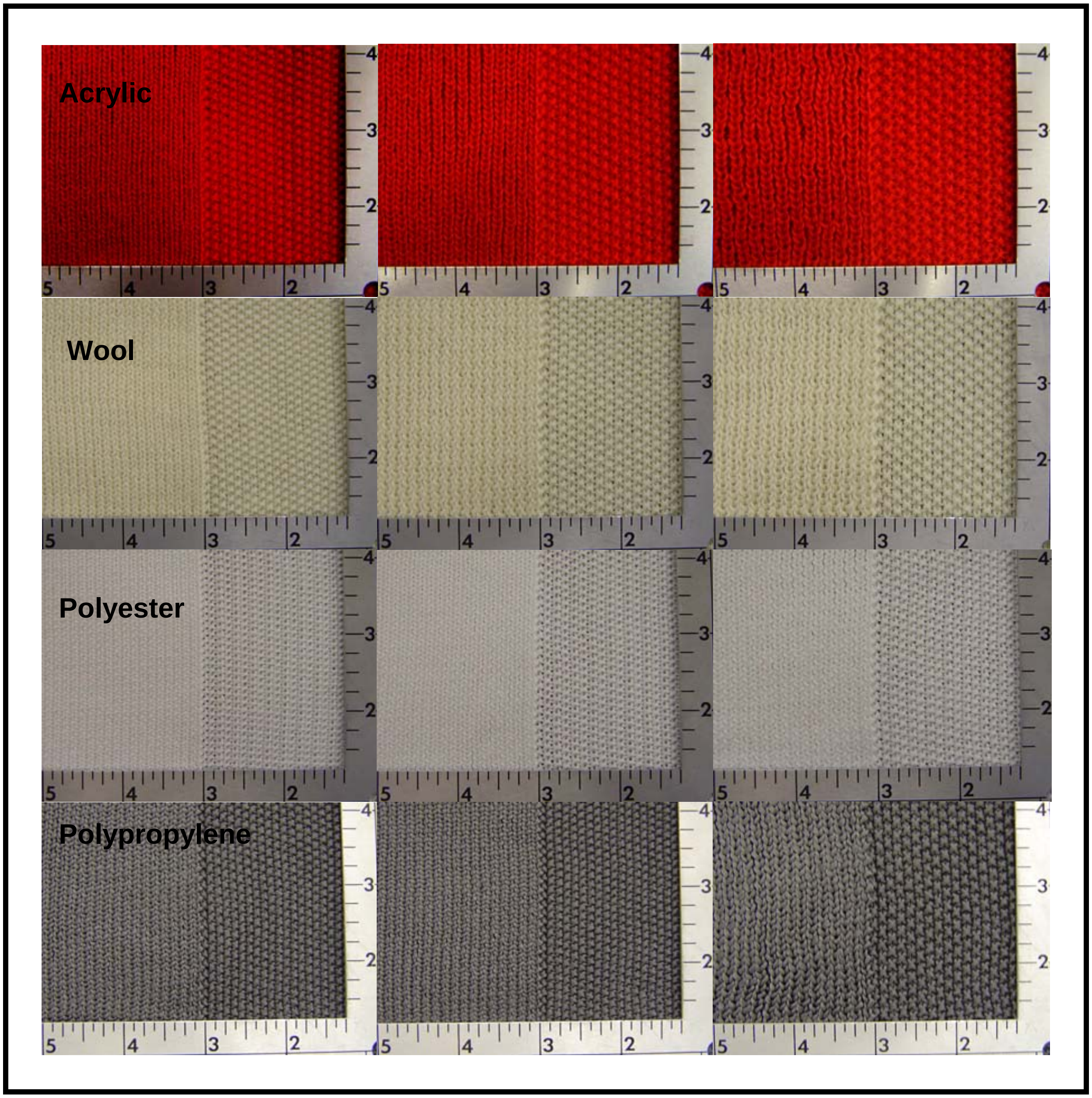

Figure A6: 1x1 Rib/Moss - Tight, Medium, Loose

APPENDIX C: TWO-STRUCTURE ARCING FABRIC

The photographs in this section represent the general concept of arc for each fabric tightness and do not reflect the raw data measurements.

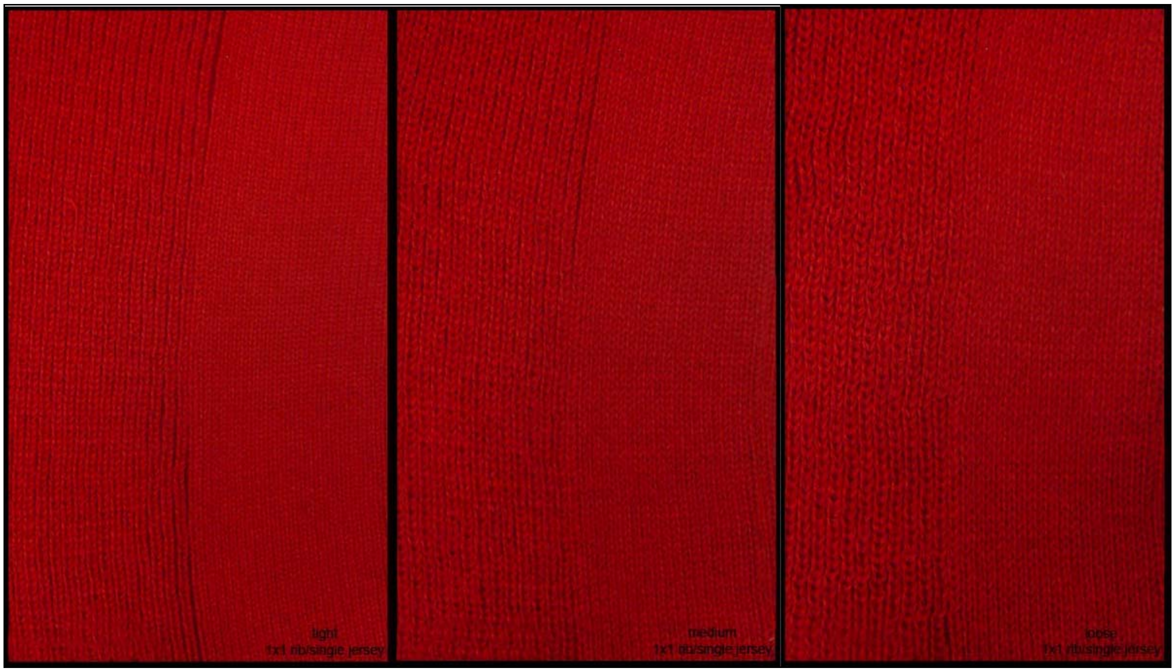

Figure A7: Acrylic - Single Jersey/1x1 Rib - Tight, Medium, Loose

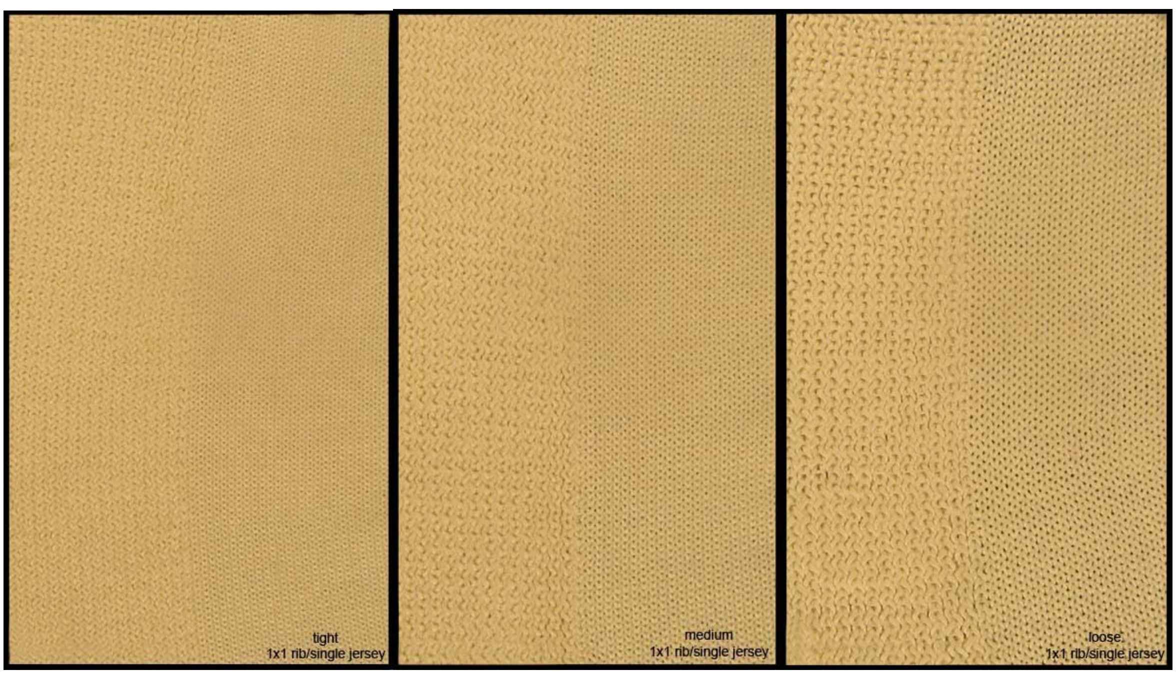

Figure A8: Wool - Single Jersey/1x1 Rib: Tight, Medium, Loose

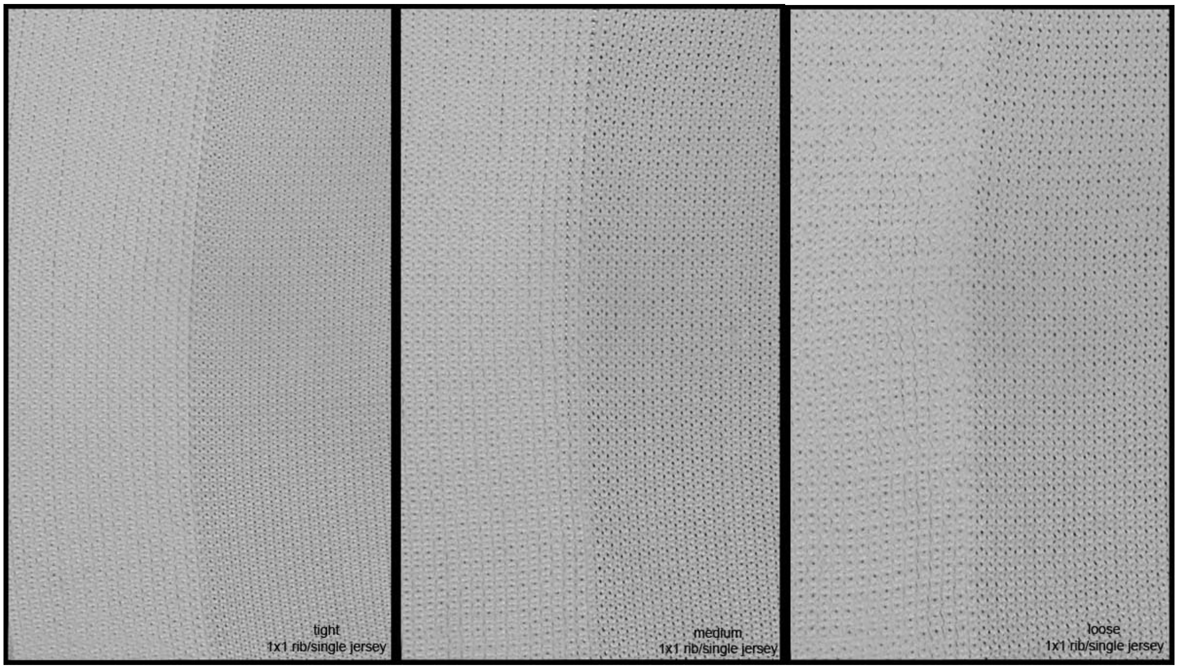

Figure A9: Polyester - Single Jersey/1x1 Rib- Tight, Medium, Loose

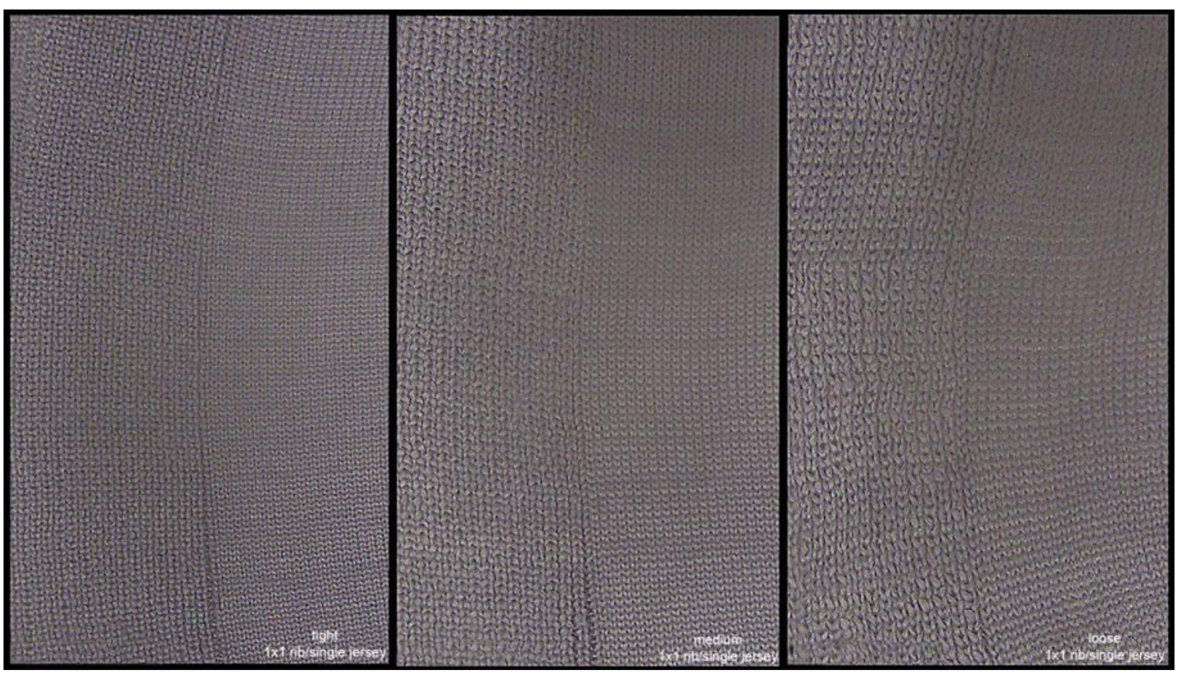

Figure A10: Polypropylene - Single Jersey/1x1 Rib- Tight, Medium, Loose

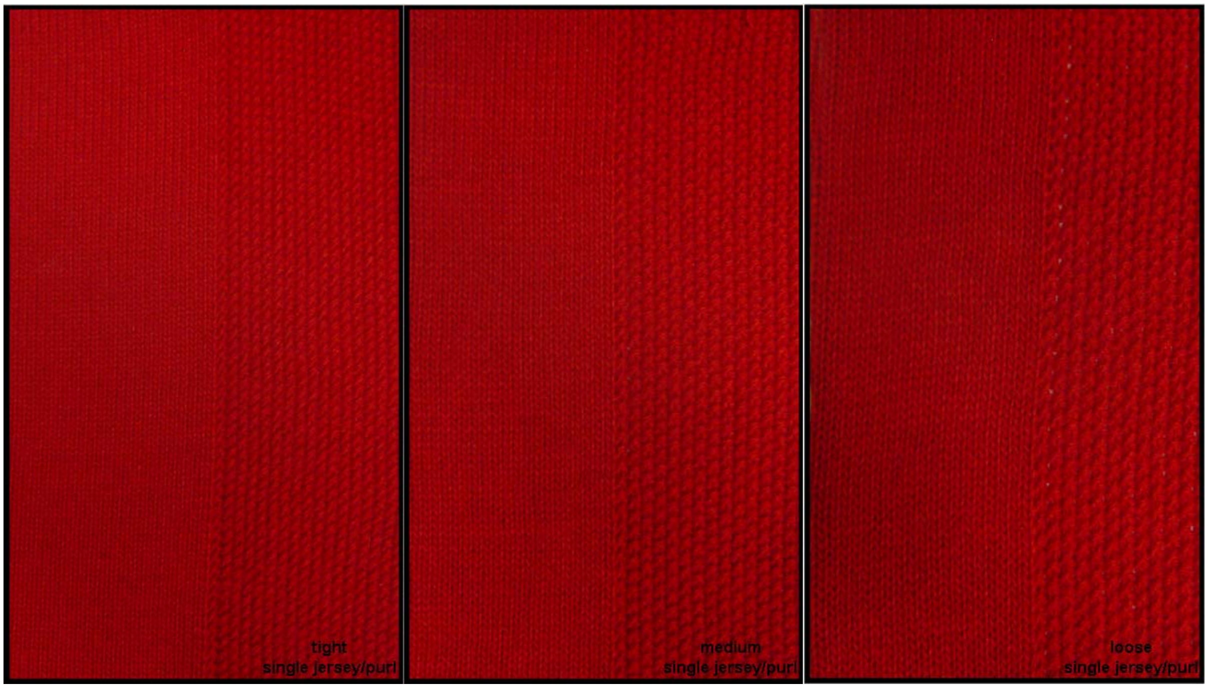

Figure A11: Acrylic - Single Jersey/Moss: Tight, Medium, Loose

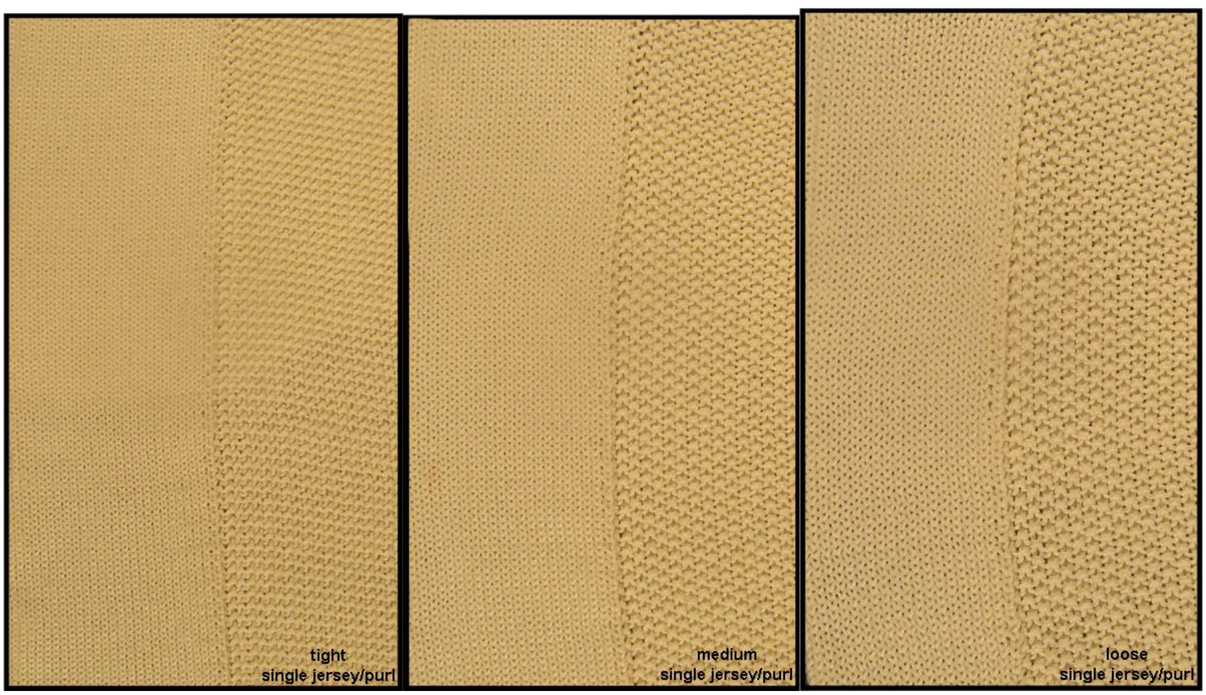

Figure A12: Wool - Single Jersey/Moss: Tight, Medium, Loose

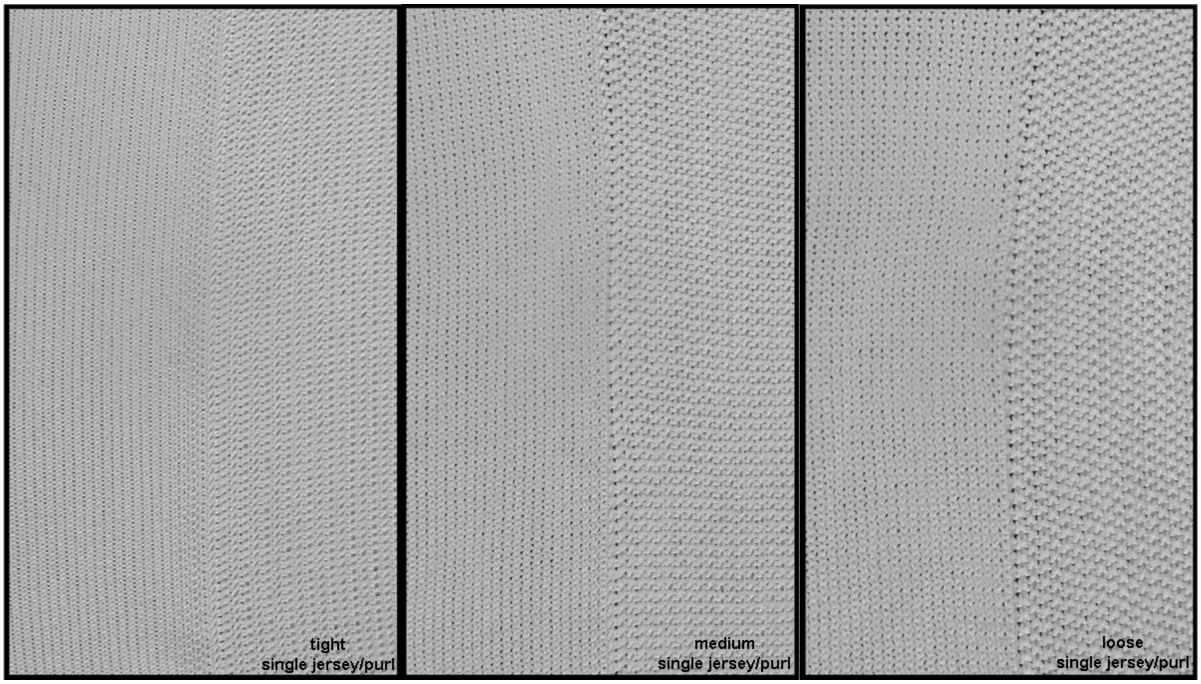

Figure A13: Polyester - Single Jersey/Moss- Tight, Medium, Loose

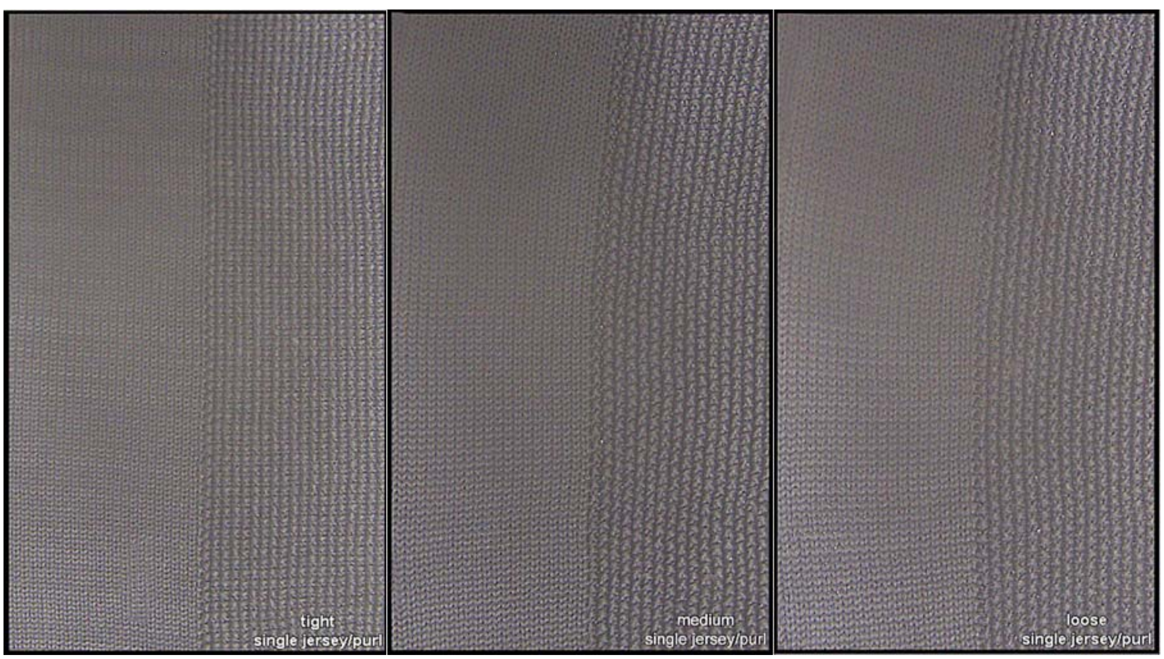

Figure A14: Polypropylene - Single Jersey/Moss- Tight, Medium, Loose

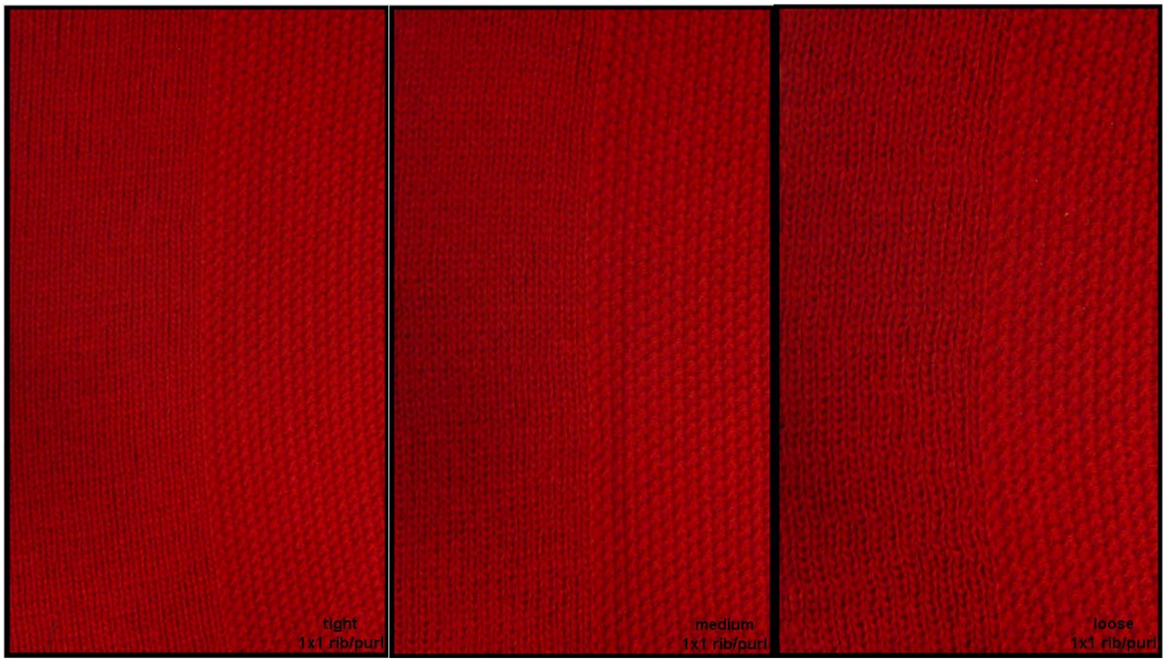

Figure A15: Acrylic - 1x1 Rib/Moss: Tight, Medium, Loose

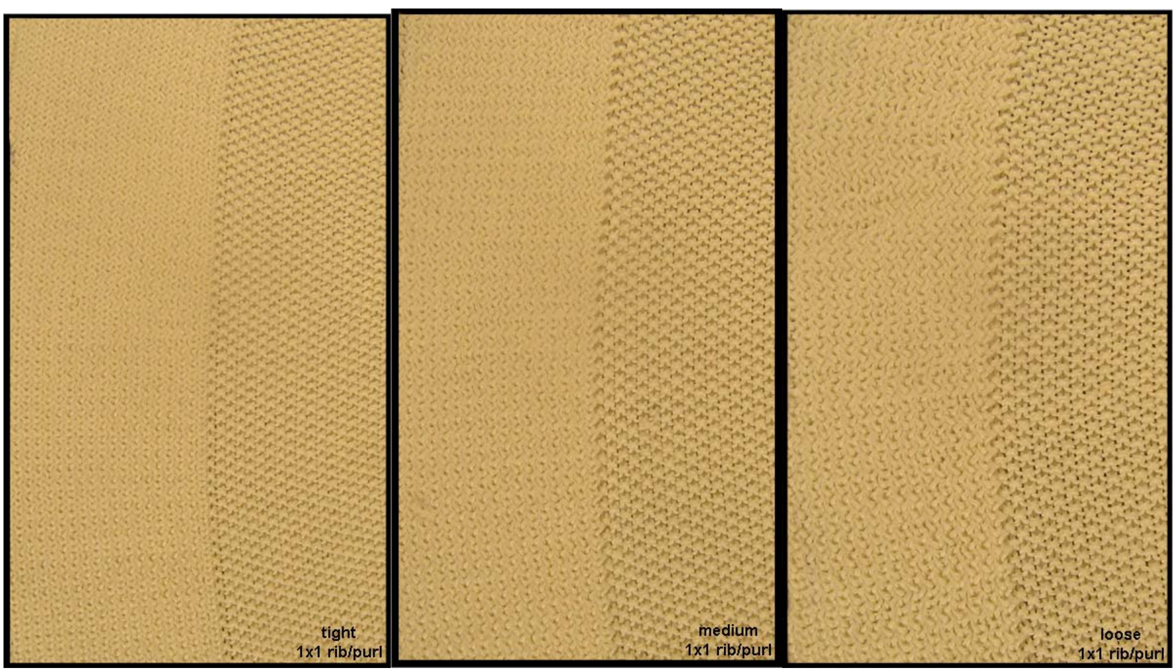

Figure A16: Wool - 1x1 Rib/Moss: Tight, Medium, Loose

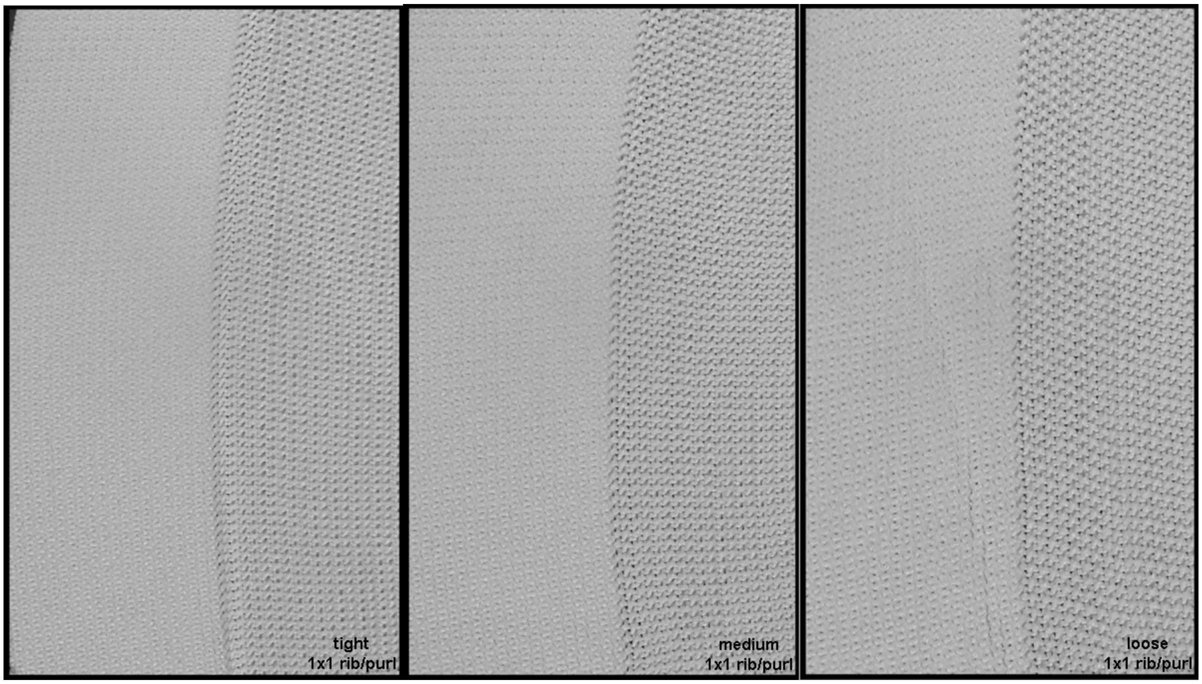

Figure A17: Polyester - 1x1 Rib/Moss- Tight, Medium, Loose

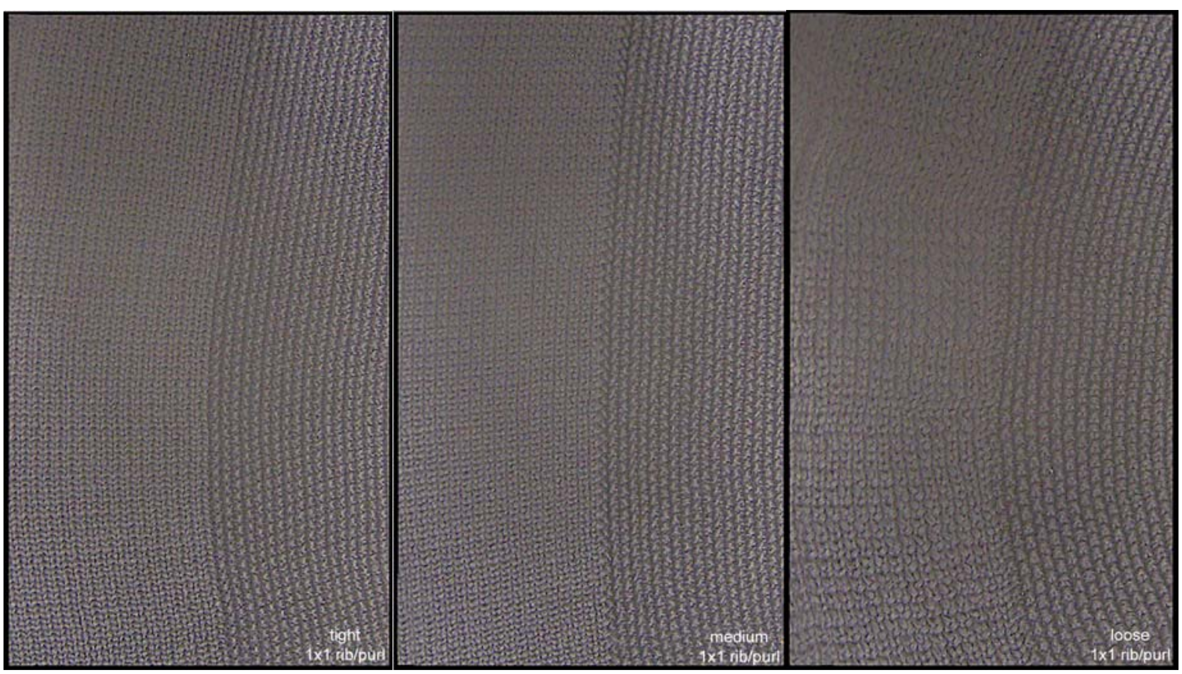

Figure A18: Polypropylene - 1x1 Rib/Moss- Tight, Medium, Loose

APPENDIX D: YARN INFORMATION

Table A1: Yarn

Fiber Type	Type	Count	Denier	# of Filaments	Denier per Filament	# Yarns Fed	Total Denier
Acrylic	spun	1/12 Worsted	664 Denier	-	-	2	1328 (low)
Wool	spun	2/48 Worsted	332 Denier	-	-	4	1328 (low)
Polyester	filament	2/300 Denier	600 Denier	136	2	2	1200 (high)
Polypropylene	filament	650 Denier	650 Denier	288	4	2	1300 (low)

APPENDIX E: VISUAL STITCH DENSITY DATA

Table A2: Acrylic

		Structure 1		Structure 1		Visual Stitch Density
		WPI	[redacted]	CPI	[redacted]	wpi x cpi
Single Jersey	Tight	9	[redacted]	21	[redacted]	189
	Medium	9	[redacted]	15	[redacted]	135
	Loose	8	[redacted]	12	[redacted]	96
			[redacted]		[redacted]	
1x1 Rib	Tight	8	[redacted]	14	[redacted]	144
	Medium	7	[redacted]	11	[redacted]	112
	Loose	7	[redacted]	9	[redacted]	84
			[redacted]		[redacted]	
Moss	Tight	8	[redacted]	18	[redacted]	112
	Medium	8	[redacted]	14	[redacted]	77
	Loose	7	[redacted]	12	[redacted]	63

		Structure 1	Structure 2	Structure 1	Structure 2	Visual Stitch Density (Ratio)
		WPI	WPI	CPI	CPI	(> cpi x wpi)/(< cpi x wpi)
Single Jersey / 1x1 Rib	Tight	11	8	17	15	1.56
	Medium	10	8	14	12	1.46
	Loose	9	7	11	10	1.41
Single Jersey / Moss	Tight	9	10	18	19	1.17
	Medium	8	9	14	14	1.13
	Loose	7	8	12	12	1.14
1x1 Rib/Moss	Tight	8	8	16	14	1.14
	Medium	8	7	12	12	1.14
	Loose	7	7	10	9	1.11

Table A3: Wool

		Structure 1		Structure 1		Visual Stitch Density
		WPI	[redacted]	**CPI**	[redacted]	**wpi x cpi**
Single Jersey	**Tight**	11	[redacted]	18	[redacted]	198
	Medium	10	[redacted]	14	[redacted]	140
	Loose	9	[redacted]	12	[redacted]	108
			[redacted]		[redacted]	
1x1 Rib	**Tight**	9	[redacted]	14	[redacted]	126
	Medium	8	[redacted]	11	[redacted]	88
	Loose	7	[redacted]	9	[redacted]	63
			[redacted]		[redacted]	
Moss	**Tight**	9	[redacted]	18	[redacted]	162
	Medium	8	[redacted]	16	[redacted]	128
	Loose	8	[redacted]	12	[redacted]	96

		Structure 1	Structure 2	Structure 1	Structure 2	Visual Stitch Density (Ratio)
		WPI	**WPI**	**CPI**	**CPI**	**(> cpi x wpi)/(< cpi x wpi)**
Single Jersey / 1x1 Rib	**Tight**	12	9	18	15	1.60
	Medium	10	8	14	13	1.35
	Loose	9	7	11	10	1.41
Single Jersey / Moss	**Tight**	10	11	20	19	1.16
	Medium	8	10	16	14	1.43
	Loose	8	9	14	11	1.43
1x1 Rib/Moss	**Tight**	10	9	20	14	1.59
	Medium	9	8	16	12	1.50
	Loose	7	8	14	10	1.60

Table A4: Polyester

		Structure 1	[redacted]	Structure 1	[redacted]	Visual Stitch Density
		WPI	[redacted]	CPI	[redacted]	wpi x cpi
Single Jersey	Tight	10	[redacted]	26	[redacted]	260
	Medium	10	[redacted]	18	[redacted]	180
	Loose	9	[redacted]	14	[redacted]	126
			[redacted]		[redacted]	
1x1 Rib	Tight	9	[redacted]	20	[redacted]	180
	Medium	9	[redacted]	15	[redacted]	135
	Loose	8	[redacted]	12	[redacted]	96
			[redacted]		[redacted]	
Moss	Tight	8	[redacted]	24	[redacted]	192
	Medium	8	[redacted]	18	[redacted]	144
	Loose	8	[redacted]	16	[redacted]	128

		Structure 1	Structure 2	Structure 1	Structure 2	Visual Stitch Density (Ratio)
		WPI	WPI	CPI	CPI	(> cpi x wpi)/(< cpi x wpi)
Single Jersey / 1x1 Rib	Tight	11	9	22	20	1.34
	Medium	10	9	16	15	1.19
	Loose	10	8	12	12	1.25
Single Jersey / Moss	Tight	9	9	25	26	1.04
	Medium	9	9	17	18	1.06
	Loose	9	8	13	14	1.21
1x1 Rib/Moss	Tight	9	9	24	20	1.20
	Medium	9	9	18	16	1.13
	Loose	8	8	16	13	1.23

Table A5: Polypropylene

		Structure 1		Structure 1		Visual Stitch Density
		WPI	[redacted]	CPI	[redacted]	wpi x cpi
Single Jersey	**Tight**	10	[redacted]	21	[redacted]	210
	Medium	10	[redacted]	17	[redacted]	170
	Loose	9	[redacted]	14	[redacted]	126
			[redacted]		[redacted]	
1x1 Rib	**Tight**	9	[redacted]	19	[redacted]	171
	Medium	8	[redacted]	15	[redacted]	120
	Loose	8	[redacted]	12	[redacted]	96
			[redacted]		[redacted]	
Moss	**Tight**	8	[redacted]	18	[redacted]	144
	Medium	8	[redacted]	18	[redacted]	144
	Loose	8	[redacted]	16	[redacted]	128

		Structure 1	Structure 2	Structure 1	Structure 2	Visual Stitch Density (Ratio)
		WPI	WPI	CPI	CPI	(> cpi x wpi)/(< cpi x wpi)
Single Jersey / 1x1 Rib	**Tight**	12	9	18	15	1.60
	Medium	11	9	13	12	1.32
	Loose	9	8	10	9	1.25
Single Jersey / Moss	**Tight**	9	11	20	19	1.29
	Medium	8	10	16	14	1.43
	Loose	8	9	14	13	1.21
1x1 Rib/Moss	**Tight**	10	9	18	15	1.33
	Medium	9	8	18	15	1.35
	Loose	7	8	12	9	1.52

APPENDIX F: WEIGHT DATA

Table A6: Weight

		Acrylic	Wool	Polyester	Polypropylene
Single Jersey	**Tight**	7.38	9.12	7.11	6.52
	Medium	6.80	7.54	5.82	6.14
	Loose	5.00	6.20	5.03	5.14
1x1 Rib	**Tight**	11.45	13.20	11.20	10.67
	Medium	9.66	11.75	9.58	9.67
	Loose	8.55	9.04	8.14	8.32
Moss	**Tight**	6.80	9.02	6.24	6.02
	Medium	5.96	7.42	5.66	5.74
	Loose	4.99	6.35	5.41	5.52
Single Jersey/1x1 Rib	**Tight**	9.95	12.04	9.32	8.67
	Medium	9.15	10.03	7.52	6.67
	Loose	7.82	7.89	6.65	5.54
Single Jersey/Moss	**Tight**	7.34	9.49	6.97	6.70
	Medium	6.37	7.54	5.74	5.56
	Loose	5.27	4.66	4.94	4.95
1x1 Rib/Moss	**Tight**	8.44	11.10	8.63	7.50
	Medium	8.16	9.45	7.69	7.39
	Loose	7.19	8.19	6.96	6.40

APPENDIX G: ARC DATA

Table A7: Acrylic- Single Jersey/1x1 Rib

TIGHT-30				MEDIUM-40				LOOSE-50			
Sample	Arc	Baseline	Arc/Baseline	Sample	Arc	Baseline	Arc/Baseline	Sample	Arc	Baseline	Arc/Baseline
1	0.63	8.50	0.07	1	0.50	8.50	0.06	1	0.25	8.50	0.03
2	0.50	8.50	0.06	2	0.63	8.50	0.07	2	0.25	8.25	0.03
3	0.50	8.50	0.06	3	0.38	8.50	0.04	3	0.25	8.25	0.03
4	0.50	8.50	0.06	4	0.38	8.50	0.04	4	0.25	8.50	0.03
5	0.50	8.25	0.06	5	0.50	8.50	0.06	5	0.50	8.25	0.06
6	0.50	8.50	0.06	6	0.38	8.50	0.04	6	0.38	8.25	0.05
7	0.50	8.25	0.06	7	0.38	8.50	0.04	7	0.25	8.25	0.03
8	0.63	8.50	0.07	8	0.38	8.50	0.04	8	0.25	8.25	0.03
9	0.63	8.50	0.07	9	0.50	8.50	0.06	9	0.25	8.25	0.03
10	0.38	8.50	0.04	10	0.50	8.50	0.06	10	0.50	8.25	0.06
11	0.50	8.50	0.06	11	0.50	8.50	0.06	11	0.50	8.25	0.06
12	0.50	8.50	0.06	12	0.50	8.50	0.06	12	0.25	8.25	0.03
13	0.50	8.50	0.06	13	0.38	8.25	0.05	13	0.50	8.25	0.06
14	0.50	8.50	0.06	14	0.50	8.50	0.06	14	0.38	8.25	0.05
15	0.50	8.50	0.06	15	0.38	8.50	0.04	15	0.25	8.25	0.03
16	0.50	8.50	0.06	16	0.38	8.75	0.04	16	0.44	8.50	0.05
17	0.38	8.50	0.04	17	0.38	8.75	0.04	17	0.50	8.50	0.06
18	0.63	8.50	0.07	18	0.38	8.75	0.04	18	0.38	8.75	0.04
19	0.50	8.50	0.06	19	0.63	8.25	0.08	19	0.50	8.50	0.06
20	0.63	8.50	0.07	20	0.38	8.50	0.04	20	0.50	8.25	0.06

Table A8: Acrylic- Single Jersey/Moss

TIGHT-30			
Sample	Arc	Baseline	Arc/Baseline
1	0.00	8.50	0.00
2	0.00	8.50	0.00
3	0.00	8.50	0.00
4	0.00	8.60	0.00
5	0.00	8.50	0.00
6	0.00	8.50	0.00
7	0.00	8.50	0.00
8	0.00	8.50	0.00
9	0.00	8.50	0.00
10	0.00	8.50	0.00
11	0.00	8.60	0.00
12	0.00	8.75	0.00
13	0.00	8.75	0.00
14	0.00	8.50	0.00
15	0.00	8.50	0.00
16	0.00	8.75	0.00
17	0.00	8.75	0.00
18	0.00	8.75	0.00
19	0.00	8.50	0.00
20	0.00	8.50	0.00

MEDIUM-40			
Sample	Arc	Baseline	Arc/Baseline
1	0.00	8.25	0.00
2	0.00	8.25	0.00
3	0.00	8.50	0.00
4	0.00	8.25	0.00
5	0.00	8.50	0.00
6	0.00	8.50	0.00
7	0.00	8.25	0.00
8	0.00	8.50	0.00
9	0.00	8.50	0.00
10	0.00	8.50	0.00
11	0.00	8.25	0.00
12	0.06	8.25	0.01
13	0.00	8.25	0.00
14	0.13	8.25	0.02
15	0.13	8.25	0.02
16	0.06	8.50	0.01
17	0.06	8.25	0.01
18	0.00	8.25	0.00
19	0.00	8.25	0.00
20	0.00	8.25	0.00

LOOSE-50			
Sample	Arc	Baseline	Arc/Baseline
1	0.00	8.25	0.00
2	0.13	8.25	0.02
3	0.06	8.25	0.01
4	0.00	8.25	0.00
5	0.13	8.25	0.02
6	0.13	8.50	0.02
7	0.00	8.25	0.00
8	0.00	8.50	0.00
9	0.06	8.25	0.01
10	0.06	8.50	0.01
11	0.13	8.25	0.02
12	0.00	8.50	0.00
13	0.00	8.50	0.00
14	0.06	8.25	0.01
15	0.06	8.00	0.01
16	0.06	8.00	0.01
17	0.00	8.00	0.00
18	0.06	8.25	0.01
19	0.13	8.25	0.02
20	0.00	8.25	0.00

Table A9: Acrylic- 1x1 Rib/Moss

TIGHT-30				MEDIUM-40				LOOSE-50			
Sample	Arc	Baseline	Arc/Baseline	Sample	Arc	Baseline	Arc/Baseline	Sample	Arc	Baseline	Arc/Baseline
1	0.50	8.25	0.06	1	0.31	8.25	0.04	1	0.25	8.00	0.03
2	0.44	8.25	0.05	2	0.63	8.25	0.08	2	0.44	8.00	0.05
3	0.69	8.00	0.09	3	0.63	8.50	0.07	3	0.50	8.00	0.06
4	0.50	8.25	0.06	4	0.44	8.25	0.05	4	0.38	8.00	0.05
5	0.69	8.25	0.08	5	0.69	8.25	0.08	5	0.63	8.00	0.08
6	0.44	8.25	0.05	6	0.50	8.25	0.06	6	0.38	8.00	0.05
7	0.38	8.50	0.04	7	0.75	8.50	0.09	7	0.50	8.00	0.06
8	0.50	8.50	0.06	8	0.50	8.00	0.06	8	0.25	8.25	0.03
9	0.69	8.25	0.08	9	0.25	7.75	0.03	9	0.38	8.00	0.05
10	0.63	8.50	0.07	10	0.50	7.75	0.06	10	0.63	8.00	0.08
11	0.50	8.25	0.06	11	0.44	8.25	0.05	11	0.50	8.00	0.06
12	0.50	8.25	0.06	12	0.44	8.00	0.05	12	0.31	8.00	0.04
13	0.38	8.25	0.05	13	0.50	8.25	0.06	13	0.50	8.00	0.06
14	0.44	8.25	0.05	14	0.63	8.00	0.08	14	0.31	8.50	0.04
15	0.38	8.25	0.05	15	0.44	8.00	0.05	15	0.38	8.50	0.04
16	0.50	8.25	0.06	16	0.69	8.25	0.08	16	0.63	8.25	0.08
17	0.50	8.25	0.06	17	0.63	8.25	0.08	17	0.31	8.25	0.04
18	0.44	8.25	0.05	18	0.69	8.00	0.09	18	0.56	8.50	0.07
19	0.44	8.00	0.05	19	0.44	8.25	0.05	19	0.44	8.50	0.05
20	0.25	8.00	0.03	20	0.38	8.25	0.05	20	0.56	8.25	0.07

Table A10: Wool- Single Jersey/1x1 Rib

TIGHT-30			
Sample	Arc	Baseline	Arc/Baseline
1	0.50	8.75	0.06
2	0.38	8.50	0.04
3	0.38	8.75	0.04
4	0.38	8.50	0.04
5	0.50	8.50	0.06
6	0.38	8.75	0.04
7	0.38	8.50	0.04
8	0.38	8.50	0.04
9	0.38	8.50	0.04
10	0.50	8.50	0.06
11	0.38	8.50	0.04
12	0.38	8.25	0.05
13	0.38	8.25	0.05
14	0.50	8.25	0.06
15	0.38	8.50	0.04
16	0.38	8.50	0.04
17	0.25	8.25	0.03
18	0.38	8.50	0.04
19	0.50	8.75	0.06
20	0.38	8.50	0.04

MEDIUM-40			
Sample	Arc	Baseline	Arc/Baseline
1	0.25	8.50	0.03
2	0.13	8.25	0.02
3	0.25	8.50	0.03
4	0.25	8.50	0.03
5	0.25	8.25	0.03
6	0.25	8.25	0.03
7	0.19	8.25	0.02
8	0.38	8.25	0.05
9	0.25	8.50	0.03
10	0.50	8.75	0.06
11	0.25	8.50	0.03
12	0.38	8.75	0.04
13	0.50	8.50	0.06
14	0.25	8.50	0.03
15	0.25	8.50	0.03
16	0.25	8.50	0.03
17	0.25	8.50	0.03
18	0.25	8.00	0.03
19	0.25	8.25	0.03
20	0.19	8.75	0.02

LOOSE-50			
Sample	Arc	Baseline	Arc/Baseline
1	0.25	8.25	0.03
2	0.19	8.25	0.02
3	0.38	8.50	0.04
4	0.25	8.25	0.03
5	0.38	8.25	0.05
6	0.38	8.50	0.04
7	0.38	8.50	0.04
8	0.38	8.50	0.04
9	0.13	8.50	0.01
10	0.13	8.25	0.02
11	0.38	8.25	0.05
12	0.25	8.25	0.03
13	0.38	8.25	0.05
14	0.44	8.50	0.05
15	0.25	8.50	0.03
16	0.38	8.25	0.05
17	0.38	8.50	0.04
18	0.25	8.50	0.03
19	0.44	8.50	0.05
20	0.25	8.50	0.03

Table A11: Wool- Single Jersey/Moss

TIGHT-30				MEDIUM-40				LOOSE-50			
Sample	Arc	Baseline	Arc/Baseline	Sample	Arc	Baseline	Arc/Baseline	Sample	Arc	Baseline	Arc/Baseline
1	0.00	8.50	0.00	1	0.06	8.00	0.01	1	0.19	8.25	0.02
2	0.06	8.50	0.01	2	0.06	8.25	0.01	2	0.13	8.25	0.02
3	0.00	8.50	0.00	3	0.13	8.00	0.02	3	0.19	8.25	0.02
4	0.13	8.50	0.02	4	0.06	8.25	0.01	4	0.19	8.50	0.02
5	0.06	8.50	0.01	5	0.06	8.25	0.01	5	0.06	8.00	0.01
6	0.06	8.50	0.01	6	0.00	8.00	0.00	6	0.19	7.75	0.02
7	0.00	8.50	0.00	7	0.06	8.25	0.01	7	0.19	8.00	0.02
8	0.00	8.50	0.00	8	0.06	8.25	0.01	8	0.06	8.00	0.01
9	0.00	8.50	0.00	9	0.06	8.00	0.01	9	0.19	8.25	0.02
10	0.00	8.50	0.00	10	0.00	8.25	0.00	10	0.38	8.25	0.05
11	0.00	8.50	0.00	11	0.06	8.00	0.01	11	0.19	8.25	0.02
12	0.00	8.50	0.00	12	0.06	8.25	0.01	12	0.13	8.25	0.02
13	0.00	8.50	0.00	13	0.25	8.25	0.03	13	0.13	8.25	0.02
14	0.00	8.50	0.00	14	0.06	8.25	0.01	14	0.13	8.00	0.02
15	0.00	8.50	0.00	15	0.06	8.00	0.01	15	0.13	8.50	0.02
16	0.00	8.50	0.00	16	0.25	8.25	0.03	16	0.13	8.00	0.02
17	0.00	8.50	0.00	17	0.13	8.25	0.02	17	0.19	7.75	0.02
18	0.00	8.25	0.00	18	0.06	7.75	0.01	18	0.13	7.75	0.02
19	0.00	8.50	0.00	19	0.38	8.00	0.05	19	0.13	7.75	0.02
20	0.00	8.50	0.00	20	0.00	8.00	0.00	20	0.13	8.00	0.02

Table A12: Wool- 1x1 Rib/Moss

TIGHT-30			
Sample	Arc	Baseline	Arc/Baseline
1	0.69	8.00	0.09
2	0.50	8.00	0.06
3	0.69	8.00	0.09
4	0.38	8.00	0.05
5	0.44	7.75	0.06
6	0.38	7.75	0.05
7	0.50	7.50	0.07
8	0.69	8.00	0.09
9	0.38	8.00	0.05
10	0.69	8.00	0.09
11	0.44	8.25	0.05
12	0.81	8.25	0.10
13	0.50	8.25	0.06
14	0.50	8.00	0.06
15	0.38	8.25	0.05
16	0.63	7.75	0.08
17	0.50	8.00	0.06
18	0.44	8.00	0.05
19	0.56	8.25	0.07
20	0.44	8.00	0.05

MEDIUM-40			
Sample	Arc	Baseline	Arc/Baseline
1	0.25	8.25	0.03
2	0.50	8.00	0.06
3	0.50	8.00	0.06
4	0.31	8.00	0.04
5	0.44	8.25	0.05
6	0.38	8.25	0.05
7	0.31	8.50	0.04
8	0.50	8.25	0.06
9	0.38	8.00	0.05
10	0.50	8.50	0.06
11	0.38	8.00	0.05
12	0.44	8.00	0.05
13	0.44	8.00	0.05
14	0.50	8.00	0.06
15	0.38	8.00	0.05
16	0.38	7.75	0.05
17	0.38	8.25	0.05
18	0.50	8.25	0.06
19	0.50	8.50	0.06
20	0.50	8.50	0.06

LOOSE-50			
Sample	Arc	Baseline	Arc/Baseline
1	0.50	7.50	0.07
2	0.50	8.00	0.06
3	0.38	8.00	0.05
4	0.50	8.00	0.06
5	0.38	8.00	0.05
6	0.38	8.00	0.05
7	0.50	8.25	0.06
8	0.38	8.00	0.05
9	0.50	8.25	0.06
10	0.50	8.00	0.06
11	0.38	8.00	0.05
12	0.50	8.00	0.06
13	0.50	8.00	0.06
14	0.50	8.25	0.06
15	0.38	8.25	0.05
16	0.38	8.00	0.05
17	0.38	8.00	0.05
18	0.38	8.00	0.05
19	0.38	8.00	0.05
20	0.63	8.00	0.08

Table A13: Polyester- Single Jersey/1x1 Rib

TIGHT-30			
Sample	Arc	Baseline	Arc/Baseline
1	0.19	8.25	0.02
2	0.25	8.50	0.03
3	0.06	8.50	0.01
4	0.13	8.25	0.02
5	0.19	8.50	0.02
6	0.25	8.50	0.03
7	0.06	8.25	0.01
8	0.00	8.38	0.00
9	0.25	8.25	0.03
10	0.13	8.50	0.02
11	0.25	8.38	0.03
12	0.19	8.50	0.02
13	0.25	8.25	0.03
14	0.25	8.25	0.03
15	0.31	8.25	0.04
16	0.31	8.25	0.04
17	0.31	8.25	0.04
18	0.38	8.25	0.05
19	0.31	8.25	0.04
20	0.25	8.50	0.03

MEDIUM-40			
Sample	Arc	Baseline	Arc/Baseline
1	0.06	8.00	0.01
2	0.00	8.25	0.00
3	0.00	8.25	0.00
4	0.00	8.50	0.00
5	0.06	8.38	0.01
6	0.00	8.25	0.00
7	0.00	8.50	0.00
8	0.06	8.25	0.01
9	0.00	8.25	0.00
10	0.06	8.00	0.01
11	0.06	8.25	0.01
12	0.00	8.25	0.00
13	0.13	8.50	0.01
14	0.00	8.25	0.00
15	0.13	8.50	0.01
16	0.00	8.50	0.00
17	0.13	8.50	0.02
18	0.06	8.38	0.01
19	0.13	8.50	0.02
20	0.06	8.38	0.01

LOOSE-50			
Sample	Arc	Baseline	Arc/Baseline
1	0.00	8.50	0.00
2	0.00	8.50	0.00
3	0.00	8.50	0.00
4	0.00	8.25	0.00
5	0.13	8.50	0.01
6	0.00	8.50	0.00
7	0.00	8.50	0.00
8	0.00	8.50	0.00
9	0.00	8.50	0.00
10	0.00	8.50	0.00
11	0.13	8.50	0.02
12	0.00	8.50	0.00
13	0.00	8.25	0.00
14	0.00	8.25	0.00
15	0.00	8.50	0.00
16	0.00	8.25	0.00
17	0.00	8.25	0.00
18	0.00	8.25	0.00
19	0.00	8.25	0.00
20	0.13	8.25	0.02

Table A14: Polyester- Single Jersey/Moss

TIGHT-30			
Sample	Arc	Baseline	Arc/Baseline
1	0.13	8.50	0.02
2	0.06	8.50	0.01
3	0.19	8.50	0.02
4	0.06	8.25	0.01
5	0.13	8.50	0.02
6	0.06	8.50	0.01
7	0.13	8.50	0.02
8	0.13	8.50	0.02
9	0.06	8.50	0.01
10	0.13	8.50	0.02
11	0.00	8.50	0.00
12	0.19	8.50	0.02
13	0.06	8.50	0.01
14	0.13	8.50	0.02
15	0.13	8.50	0.02
16	0.06	8.25	0.01
17	0.13	8.50	0.02
18	0.06	8.50	0.01
19	0.06	8.50	0.01
20	0.13	8.50	0.02

MEDIUM-40			
Sample	Arc	Baseline	Arc/Baseline
1	0.19	8.25	0.02
2	0.06	8.25	0.01
3	0.13	8.00	0.02
4	0.06	8.25	0.01
5	0.13	8.25	0.02
6	0.25	8.25	0.03
7	0.19	8.25	0.02
8	0.00	8.25	0.00
9	0.00	8.25	0.00
10	0.06	8.25	0.01
11	0.25	8.00	0.03
12	0.31	8.25	0.04
13	0.19	8.25	0.02
14	0.13	8.25	0.02
15	0.25	8.25	0.03
16	0.25	8.00	0.03
17	0.13	8.25	0.02
18	0.19	8.00	0.02
19	0.25	8.00	0.03
20	0.00	8.50	0.00

LOOSE-50			
Sample	Arc	Baseline	Arc/Baseline
1	0.19	8.00	0.02
2	0.19	8.00	0.02
3	0.13	8.25	0.02
4	0.31	8.25	0.04
5	0.19	8.00	0.02
6	0.31	8.00	0.04
7	0.31	8.00	0.04
8	0.19	8.00	0.02
9	0.38	8.00	0.05
10	0.13	8.00	0.02
11	0.19	8.50	0.02
12	0.25	8.00	0.03
13	0.25	8.00	0.03
14	0.13	8.00	0.02
15	0.25	8.00	0.03
16	0.00	7.58	0.00
17	0.44	8.00	0.05
18	0.19	8.50	0.02
19	0.13	8.00	0.02
20	0.38	8.00	0.05

Table A15: Polyester- 1x1 Rib/Moss

TIGHT-30			
Sample	Arc	Baseline	Arc/Baseline
1	0.38	8.00	0.05
2	0.38	8.25	0.05
3	0.38	8.00	0.05
4	0.50	8.25	0.06
5	0.50	8.00	0.06
6	0.31	8.25	0.04
7	0.50	8.00	0.06
8	0.31	8.00	0.04
9	0.50	8.00	0.06
10	0.38	8.00	0.05
11	0.31	8.25	0.04
12	0.50	8.00	0.06
13	0.38	8.25	0.05
14	0.38	8.25	0.05
15	0.44	8.25	0.05
16	0.38	8.25	0.05
17	0.25	8.25	0.03
18	0.31	8.25	0.04
19	0.44	8.25	0.05
20	0.06	8.25	0.01

MEDIUM-40			
Sample	Arc	Baseline	Arc/Baseline
1	0.38	8.00	0.05
2	0.38	8.25	0.05
3	0.50	8.00	0.06
4	0.44	8.00	0.05
5	0.25	8.25	0.03
6	0.25	8.00	0.03
7	0.31	8.25	0.04
8	0.38	8.00	0.05
9	0.06	8.25	0.01
10	0.31	8.00	0.04
11	0.44	8.00	0.05
12	0.25	8.00	0.03
13	0.31	8.00	0.04
14	0.38	8.25	0.05
15	0.44	8.00	0.05
16	0.31	8.00	0.04
17	0.31	8.00	0.04
18	0.56	8.00	0.07
19	0.06	7.50	0.01
20	0.19	7.50	0.03

LOOSE-50			
Sample	Arc	Baseline	Arc/Baseline
1	0.31	8.25	0.04
2	0.38	8.25	0.05
3	0.06	8.00	0.01
4	0.38	8.00	0.05
5	0.38	8.25	0.05
6	0.06	8.00	0.01
7	0.44	8.00	0.05
8	0.56	8.25	0.07
9	0.44	8.00	0.05
10	0.56	8.00	0.07
11	0.44	7.50	0.06
12	0.25	7.75	0.03
13	0.56	8.00	0.07
14	0.50	7.75	0.06
15	0.50	8.00	0.06
16	0.50	8.00	0.06
17	0.50	8.00	0.06
18	0.38	7.75	0.05
19	0.31	8.00	0.04
20	0.44	8.00	0.05

Table A16: Polypropylene- Single Jersey/1x1 Rib

TIGHT-30			
Sample	Arc	Baseline	Arc/Baseline
1	1.50	8.25	0.18
2	0.50	8.50	0.06
3	0.25	8.50	0.03
4	0.25	8.50	0.03
5	0.19	8.25	0.02
6	0.19	8.25	0.02
7	0.19	8.50	0.02
8	0.25	8.50	0.03
9	0.38	8.50	0.04
10	0.25	8.50	0.03
11	0.31	8.50	0.04
12	0.25	8.25	0.03
13	—	—	—
14	—	—	—
15	—	—	—
16	—	—	—
17	—	—	—
18	—	—	—
19	—	—	—
20	—	—	—

MEDIUM-40			
Sample	Arc	Baseline	Arc/Baseline
1	0.00	8.25	0.00
2	0.19	8.25	0.02
3	0.06	8.25	0.01
4	0.06	8.25	0.01
5	0.25	8.00	0.03
6	0.25	8.25	0.03
7	0.19	8.38	0.02
8	0.00	8.00	0.00
9	0.19	8.00	0.02
10	0.00	8.50	0.00
11	0.00	8.25	0.00
12	0.06	8.25	0.01
13	0.00	8.25	0.00
14	0.06	8.50	0.01
15	0.00	8.50	0.00
16	0.06	8.25	0.01
17	0.06	8.25	0.01
18	0.13	8.25	0.02
19	0.25	8.25	0.03
20	0.06	8.25	0.01

LOOSE-50			
Sample	Arc	Baseline	Arc/Baseline
1	0.00	8.25	0.00
2	0.00	8.00	0.00
3	0.00	8.25	0.00
4	0.00	8.25	0.00
5	0.00	8.25	0.00
6	0.00	8.00	0.00
7	0.00	8.00	0.00
8	0.00	8.00	0.00
9	0.00	8.00	0.00
10	0.25	7.75	0.03
11	0.13	7.50	0.02
12	0.13	7.75	0.02
13	0.31	8.00	0.04
14	0.31	8.00	0.04
15	0.00	8.00	0.00
16	0.00	8.50	0.00
17	0.06	8.50	0.01
18	0.13	8.25	0.02
19	0.25	8.50	0.03
20	0.13	7.75	0.02

Table A17: Polypropylene- Single Jersey/Moss

TIGHT-30			
Sample	Arc	Baseline	Arc/Baseline
1	0.00	8.25	0.00
2	0.00	8.25	0.00
3	0.00	8.25	0.00
4	0.00	8.25	0.00
5	0.00	8.25	0.00
6	0.00	8.25	0.00
7	0.00	8.50	0.00
8	0.00	8.50	0.00
9	0.00	8.50	0.00
10	0.00	8.25	0.00
11	0.00	8.50	0.00
12	0.13	8.50	0.02
13	0.06	8.50	0.01
14	0.13	8.25	0.02
15	0.06	8.50	0.01
16	0.00	8.25	0.00
17	0.06	8.25	0.01
18	—	—	—
19	—	—	—
20	—	—	—

MEDIUM-40			
Sample	Arc	Baseline	Arc/Baseline
1	0.19	8.00	0.02
2	0.13	8.00	0.02
3	0.13	8.00	0.02
4	0.25	8.25	0.03
5	0.13	8.50	0.02
6	0.06	8.50	0.01
7	0.25	8.50	0.03
8	0.13	8.25	0.02
9	0.13	8.00	0.02
10	0.25	8.25	0.03
11	0.19	8.50	0.02
12	0.38	8.25	0.05
13	0.31	8.00	0.04
14	0.25	8.25	0.03
15	0.06	8.25	0.01
16	0.13	8.25	0.02
17	0.13	8.25	0.02
18	0.38	7.75	0.05
19	0.06	8.00	0.01
20	0.13	7.75	0.02

LOOSE-50			
Sample	Arc	Baseline	Arc/Baseline
1	0.13	8.25	0.02
2	0.06	8.00	0.01
3	0.13	8.00	0.02
4	0.13	8.00	0.02
5	0.13	8.00	0.02
6	0.19	8.00	0.02
7	0.06	8.25	0.01
8	0.25	8.25	0.03
9	0.13	8.25	0.02
10	0.19	8.00	0.02
11	0.38	8.00	0.05
12	0.06	8.00	0.01
13	0.25	8.00	0.03
14	0.06	8.25	0.01
15	0.06	8.00	0.01
16	0.06	8.25	0.01
17	0.25	8.00	0.03
18	0.25	7.50	0.03
19	0.25	7.50	0.03
20	0.19	7.75	0.02

Table A18: Polypropylene- 1x1 Rib/Moss

TIGHT-30			
Sample	Arc	Baseline	Arc/Baseline
1	0.38	8.25	0.05
2	0.44	8.25	0.05
3	0.38	8.25	0.05
4	0.31	8.00	0.04
5	0.19	8.00	0.02
6	0.31	8.00	0.04
7	0.25	8.50	0.03
8	0.50	8.25	0.06
9	0.31	8.25	0.04
10	0.38	8.25	0.05
11	0.19	8.25	0.02
12	0.63	8.25	0.08
13	0.25	8.00	0.03
14	0.31	8.00	0.04
15	0.44	8.00	0.05
16	—	—	—
17	—	—	—
18	—	—	—
19	—	—	—
20	—	—	—

MEDIUM-40			
Sample	Arc	Baseline	Arc/Baseline
1	0.13	8.25	0.02
2	0.06	8.25	0.01
3	0.25	8.50	0.03
4	0.25	8.50	0.03
5	0.06	8.25	0.01
6	0.38	8.25	0.05
7	0.31	8.50	0.04
8	0.25	8.25	0.03
9	0.13	8.25	0.02
10	0.75	8.00	0.09
11	0.13	8.50	0.02
12	0.31	8.25	0.04
13	0.13	8.00	0.02
14	0.31	8.00	0.04
15	0.25	7.75	0.03
16	—	—	—
17	—	—	—
18	—	—	—
19	—	—	—
20	—	—	—

LOOSE-50			
Sample	Arc	Baseline	Arc/Baseline
1	0.38	8.25	0.05
2	0.75	8.00	0.09
3	0.63	8.00	0.08
4	0.63	8.00	0.08
5	1.00	7.50	0.13
6	0.88	8.25	0.11
7	0.50	8.00	0.06
8	0.75	8.00	0.09
9	0.38	8.00	0.05
10	0.38	8.25	0.05
11	0.75	7.25	0.10
12	0.25	8.25	0.03
13	0.38	8.00	0.05
14	0.44	8.00	0.05
15	0.06	8.25	0.01
16	0.75	8.00	0.09
17	0.06	8.25	0.01
18	0.06	7.75	0.01
19	0.63	7.25	0.09
20	0.63	7.30	0.09

APPENDIX H: STATISTICAL ANALYSIS DATA

Table A19: Tight Fabric and Medium Fabric

t-Test: Two-Sample Assuming Unequal Variances

	Tight	Medium
	Variable 1	*Variable 2*
Mean	0.034093	0.028627
Variance	0.000766	0.000522
Observations	224	235
Hypothesized Mean Difference	0	
df	433	
t Stat	2.301023	
P(T<=t) two-tail	0.021865	
t Critical two-tail	1.965459	

Table A20: Tight Fabric and Loose Fabric

t-Test: Two-Sample Assuming Unequal Variances

	Tight	Loose
	Variable 1	*Variable 2*
Mean	0.034093	0.032794
Variance	0.000766	0.000642
Observations	224	240
Hypothesized Mean Difference	0	
df	451	
t Stat	0.526203	
P(T<=t) two-tail	0.599006	
t Critical two-tail	1.965236	

Table A21: Medium Fabric and Loose Fabric

t-Test: Two-Sample Assuming Unequal Variances

	Medium	Loose
	Variable 1	*Variable 2*
Mean	0.028627	0.032794
Variance	0.000522	0.000642
Observations	235	240
Hypothesized Mean Difference	0	
df	470	
t Stat	-1.88273	
P(T<=t) two-tail	0.060354	
t Critical two-tail	1.965022	

Table A22: Single Jersey/1x1 Rib Fabric and Single Jersey/Moss Fabric

t-Test: Two-Sample Assuming Unequal Variances

	Single Jersey/1x1 Rib	Single Jersey/Moss
	Variable 1	*Variable 2*
Mean	0.030836507	0.012344238
Variance	0.000561857	0.000156875
Observations	232	237
Hypothesized Mean Difference	0	
Df	349	
t Stat	10.53059342	
P(T<=t) two-tail	1.05838E-22	
t Critical two-tail	1.966782293	

Table A23: Single Jersey/1x1 Rib Fabric and 1x1 Rib/Moss Fabric

t-Test: Two-Sample Assuming Unequal Variances

	Single Jersey/1x1 Rib	1x1 Rib/Moss
	Variable 1	*Variable 2*
Mean	0.030836507	0.052848221
Variance	0.000561857	0.000400362
Observations	232	230
Hypothesized Mean Difference	0	
df	449	
t Stat	-10.7888871	
P(T<=t) two-tail	2.75771E-24	
t Critical two-tail	1.965263436	

Table A24: Single Jersey/Moss Fabric and 1x1 Rib/Moss Fabric

t-Test: Two-Sample Assuming Unequal Variances

	Single Jersey/Moss	1x1 Rib/Moss
	Variable 1	*Variable 2*
Mean	0.012344238	0.052848221
Variance	0.000156875	0.000400362
Observations	237	230
Hypothesized Mean Difference	0	
df	383	
t Stat	-26.130934	
P(T<=t) two-tail	3.86166E-87	
t Critical two-tail	1.966177479	

Table A25: Spun Yarn and Filament Yarn

t-Test: Two-Sample Assuming Unequal Variances

	Spun	Filament
	Variable 1	*Variable 2*
Mean	0.037087492	0.02620427
Variance	0.000642415	0.000588788
Observations	360	339
Hypothesized Mean Difference	0	
df	697	
t Stat	5.799685955	
P(T<=t) two-tail	1.00763E-08	
t Critical two-tail	1.963371687	

Table A26: Acrylic Yarn and Wool Yarn

t-Test: Two-Sample Assuming Unequal Variances

	Acrylic	Wool
	Variable 1	*Variable 2*
Mean	0.03824313	0.035931855
Variance	0.000772489	0.000513244
Observations	180	180
Hypothesized Mean Difference	0	
df	344	
t Stat	0.864793754	
P(T<=t) two-tail	0.387754646	
t Critical two-tail	1.966882337	

Table A27: Polyester Yarn and Wool Yarn

t-Test: Two-Sample Assuming Unequal Variances

	Polyester	Polypropylene
	Variable 1	*Variable 2*
Mean	0.025510695	0.02698945
Variance	0.000411084	0.000792669
Observations	180	159
Hypothesized Mean Difference	0	
df	283	
t Stat	-0.548472344	
P(T<=t) two-tail	0.583800023	
t Critical two-tail	1.968383003	